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NAVIGATIONAL CHECKING: A MODEL OF ELEVATION ANGLE EFFECTS, IMAGE COMPLEXITY, AND FEATURE TYPE

BY

JOSEPH CHARLES HICKOX

B.S., United States Air Force Academy, 1987

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Psychology
in the Graduate College of the
University of Illinois at Urbana-Champaign, 1997

Urbana, Illinois

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

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JOSEPH CHARLES HICKOX

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THE DEGREE OF MASTER OF SCIENCE

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Christopher D. Wickens — Chairperson

Nadine Sarter

† Required for doctor's degree but not for master's.

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Joseph Charles Hickox, M.S.
Department of Psychology
University of Illinois at Urbana-Champaign, 1997
Christopher D. Wickens, Advisor

This study sought to examine the effects of different manipulations of map displays on the task of navigational checking. It was hypothesized that the latency associated with egolocation determination was not governed by a function of the angular disparity, as traditional mental rotation studies ascribe, but by a function of the sin of the angles involved. Therefore, the primary independent variable of interest was the amount of difference between the sin of the elevation angles of the map and the sin of the elevation angles of the Forward Field of View (FFOV). Additionally, the effects of complexity and feature type (defined by man-made vs. natural) were also investigated. A same/different paradigm was employed as subjects compared realistic navigation scenes presented on a computer screen to simulate the electronic "map" and a large projector screen to simulate the "FFOV". The dependent measures were response time and accuracy. Significant main effects were found for the sin disparity of the map and FFOV, complexity, and feature type. Significant interactions were found for sin disparity and feature type, and complexity and feature type. Additionally, significant main effects of trial type (same or different) and a significant interaction with complexity were investigated in an effort to examine subject search strategy. Conclusions were made based upon the findings and their implications for the design of 3-D electronic maps.

Acknowledgments

I would like to credit all of the individuals who contributed to this effort. Thanks go to Dr. Chris Wickens for his countless contributions and dedication to the education of his students and to Dr. Nadine Sarter for her additional guidance. Further recognition goes to Sharon Yeakel for her programming skills, without which this project could never have been initiated. I would also like to thank my wife and family for selflessly supporting me as I labored through this project. This research was funded by contract N000014-93-1-0253 from the Naval Air Warfare Center Weapons Division, China Lake, California. Bob Osgood and Jan Stiff were technical and scientific monitors.

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Introduction

Fundamental to the skills of any aviator is the ability to always know where he is and where he is going. To a novice, viewing the world from the air is a very unique sight. It is often difficult to recognize or even identify known features and landmarks. Air navigation creates a unique set of cognitive demands as a pilot or navigator repeatedly compares features of the map with the outside view or forward field of view (FFOV), and quickly determines whether or not the two are congruent (Aretz, 1991). In this task, referred to as "navigational checking" (Wickens, Schreiber & Renner, 1994), features in the FFOV that are compared with the map could be single entities, or an aggregation of features, such as road intersections, a group of buildings or a series of river bends, etc. The mental processing and cognitive requirements imposed on the navigator engaged in navigational checking are complex and these are detailed in a model that is presented in depth later in this paper.

The need for accuracy in this task is self-evident, as getting "lost" in the air can have dire consequences (Williams, Hutchinson & Wickens, 1996). Likewise, speed should also be given a high priority in the determination of congruence or incongruence. As an example, consider a fighter aircraft on the final leg of a bombing run over hostile unfamiliar enemy territory. As he approaches the objective area, he needs to be able to identify the target rapidly in order to program his weapons guidance systems. The cost of misidentifying the target can not be overstated as the consequences of bombing the wrong target can be disastrous. During the Persian Gulf War, several highly publicized examples of bombing wrong targets resulted not only in civilian loss of life, but also losses to our own troops in so called "friendly fire" incidents (Bond, 1991; Hackworth, 1991). At the same time, with the speeds that some modern fighters can attain, it is conceivable that an aircraft would only be in the target zone for a few seconds. Identification of the target needs to be timely and accurate. Although many of the guidance systems in today's modern aircraft are automatic, guided by computers, internal navigation and global positioning, target confirmation and engagement still depends upon the pilot visually identifying the target; and pilot performance will always remain critical should automation fail.

Navigational checking is not limited to fighter pilots on bombing run. A very different example would be provided by an aircraft flying through the clouds toward the final approach to an airport. At the moment the pilot breaks out of the weather, she needs to be able to quickly

determine the congruence of her FFOV with her map. Similar criticality would characterize a helicopter on a low altitude missions. Several recent examples of wrong airport landings in visual meteorological conditions graphically illustrate the breakdowns of the navigational checking process. (Antunano, Mohler, and Gosbee, 1989; Meares, 1995)

The previous examples were of aircraft flying at lower altitudes; however, navigational checking is applicable to high-altitude flight. When not flying on instruments at cruise altitudes, pilots are still engaged in navigational checking. Although time is not as critical in cruise flight, pilots still need to reference a map and determine congruence with their FFOV. In this case, if the two visual images are not congruent, the possible implications are that the aircraft could have veered off course slightly and only a small correction may be needed, or the pilot may be significantly off course and have to determine her position by other means, e.g. inertial guidance, radio navigation or air traffic control. Either way, the cost of incongruence is mitigated by the higher altitude and the greater time available to make a correction. Both a fighter on a bombing run and an aircraft on final approach have limited options when the two views are incongruent; time is much more critical. The inference is that navigational checking is a continuous process and is desirable or necessary during every flight phase in which the ground is visible.

The nature of navigational checking varies with the aircraft's particular phase of flight. The pilot of an aircraft in cruise flight (usually quite high) will be interested in several different viewing different angles in his FFOV (see figure 1.1). He may be looking almost straight down (-90°), a difficult task given the nature and design of most aircraft, or he could be looking several miles ahead of the aircraft, resulting in lower viewing elevation angles. In contrast, the pilot of an aircraft on a supply airdrop, bombing run or final approach at altitudes below 500 ft., would be less interested in what was at large viewing angles directly beneath, or at steep elevation angles in front of the aircraft and more interested looking ahead of the aircraft yielding smaller viewing angles. Similar distance ahead will yield smaller viewing angles as the altitude is lower.

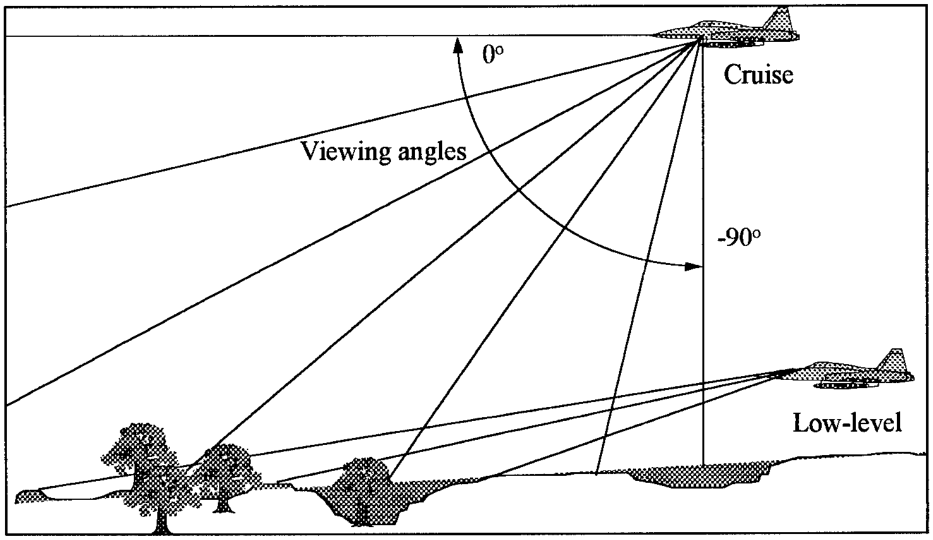


Figure 1.1- Comparison of different FFOV angles

The design problem

It is important to reiterate the type of meteorological conditions that are assumed to exist within the paradigm of the navigational checking task. Although it is unlikely that any pilot would venture into the air without some form of radio navigational aid available to assist in navigation, the paradigm at present assumes that navigational checking is strictly a visual task, accomplished under visual flight rules (VFR). This assumption becomes most relevant during less standardized missions into areas that are not well known or well serviced by ground navigational aids, such as military combat sorties, medical evacuations, and search and rescue missions. In these types of scenarios, time is critical and consequences of navigational errors are severe.

Traditionally, general aviation and airline pilots flying under visual meteorological conditions (VMC) have been limited to paper aeronautical charts or maps generated by NOAA (National Oceanic and Atmospheric Association) or Jeppesen Corp. Such navigational charts are drawn on a scale of 1 to 500,000. Military pilots have access to the National Imagery and Mapping Agency (NIMA) which provides a much wider range of map scales including Operational Navigation Charts (ONC) scaled at 1 to 1,000,000; Tactical Pilotage Charts (TPC), as with the civilian sectional counterpart scaled at 1 to 500,000. Joint Operations Graphics (JOG), scaled at 1 to 250,000, and Topographical Line Maps (TLM) drawn at 1 to 100,000 or 1 to 50,000 are used for lower level tactical navigation and target/objective area identification. By using a smaller scale map, resolution is improved, hence providing more detail and greater

numbers of features available, important considerations when flying low to the ground. Other charts that are used for navigational purposes; such as approach plates of the terminal or objective area are also available and are generated at scales as small as 1 to 10,000. Although primarily used for instrument procedures, these charts are often used for visual navigation purposes to assist when instrument procedures are not necessary and other navigational charts are not available. Additionally, the military uses other media such as satellite or high altitude imagery, or tactical photos made by a reconnaissance aircraft primarily to aid in target acquisition, but also in navigation. Regardless of scale, each medium; however, has been limited in its respective view, typically a top-down (-90°) perspective.

With the advent of modern computerized navigational systems and precision guidance such as GPS (Global Positioning System), commercial, military and general aviation (on a much smaller scale) have been replacing traditional paper aeronautical charts with sophisticated moving map displays (see figure 1.2a). Two of the largest motivations for such development are the cost savings of eliminating the paper charts, and the ease of updating electronically stored information compared to paper charts. In light of this, recent studies have compared the use of electronic and paper maps in instrument approach procedure (IAP) charts. In two of the studies, objective data yielded inconsistent differences between the two (Mykityshyn, Kuchar, and Hansman, 1994; Hannon, 1994); however, Hofer, Palen, Higman, Infield & Possolo (1992) and Hofer (1993) found that faster information retrieval times for decluttered electronic charts (IAP's) than for paper ones. Additionally, in all of the studies, pilots consistently preferred a north-up electronic moving map to a traditional paper map.

As with paper aeronautical charts, most operational electronic moving map displays have been limited to a top down view(-90° perspective). With the addition of digitized terrain databases, 3-dimensional renderings of an area are now possible, eliminating the exclusivity of the 90° map perspective (see figure 1.2b). With the available computer technology, one of the more notable features inherent in the design of electronic maps is the customization of features available. Such customization could be pilot selectable and might include overlaying the terrain depiction with aeronautical chart information, adding or deleting information from the chart, selecting fixed vs. rotating map perspectives, 2-D or 3-D renderings, static or dynamic images, and scaling or zooming functions.

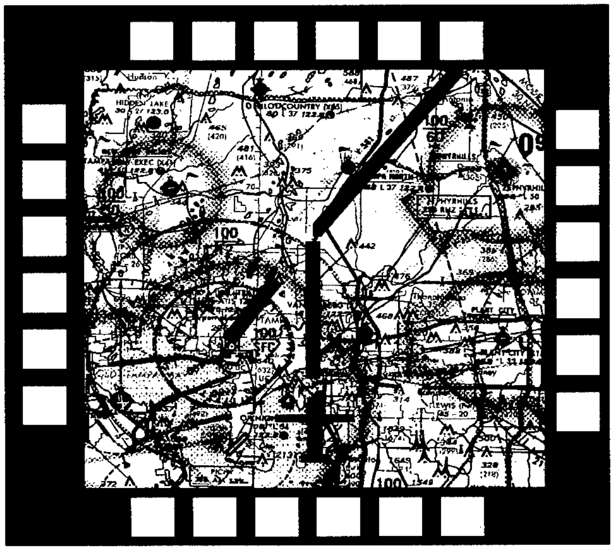


Figure 1.2a. Generic 2-D moving map display digitized paper chart

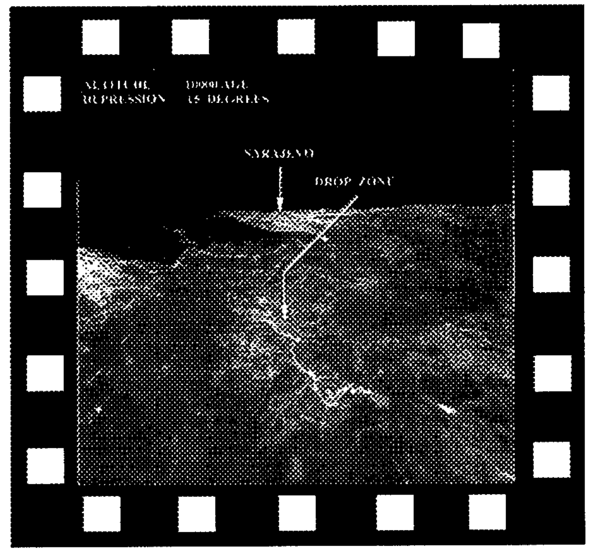


Figure 1.2b. 3-D perspective of a drop using zone in Bosnia-Herzegovina based on satellite imagery: (Note: From "Given' 'em their Space: Peacekeeping forces in Bosnia relay on 'high-ground' support" by T.P. Barella, 1996, Airman Magazine,40(6), p. 5. non-copyrighted material.

At this point it is meaningful to highlight two assumptions that can be made with regard to navigational checking and its implications for electronic map design. First, the task itself is analogous to the classic "same-different" object comparison paradigm (Posner, 1978; Shepard & Metzlar, 1971) Secondly, comparisons between the map and the FFOV will be fastest and most accurate when the two views have close physical identity. This has been shown in several object comparison studies (Cooper & Podgorny, 1976; Doane, Alderton, Sohn, & Pellegrino, 1994; Pylyshun, 1979) and also within the navigational checking paradigm (Schreiber, Wickens, Alton & Renner, 1996). With the increasing availability of different presentation options, it may be tempting to integrate every available feature into this type of display so that the FFOV and the electronic map are close in physical identity. However, if there is a requirement for continuous map updating, driven by aircraft motion, then the technological demands on such a system at present are computationally and financially cost prohibitive. The issue confronted by electronic map designers is how to configure maps with available features so that they can best serve the navigational checking task, within the context of technological feasibility. In other words, in light of the technological constraints, how much can the physical identity of the map with the FFOV be degraded and still support efficient navigational checking? The answer to this question should be

derivable from a valid information processing model that reveals the source of the cognitive transformations necessary to accomplish this task.

Navigational checking model

Restated, navigational checking is defined as the task in which the navigator engages in a continuous cross check between a map and the forward field of view (FFOV), to determine if the two are congruent; and hence, if geographical orientation is maintained. While the process is generally continuous, it can be modeled as a series of discrete matches, initiated by scanning, comparing two visual images. In fact, sometimes the discrete trial is a totally valid representation, as when the pilot suddenly breaks out of the clouds and is required to confirm his or her location; or when a ground target element suddenly appears in sight, and the flyer is required to verify that it is the same target as the destination on the map.

A graphical model of the navigational checking task adapted from Wickens & Hickox (in press) which can be used to integrate the relevant research findings, is shown in figure 1.3 (page 7). The model represents the task by the comparison of two "images", the map stimulus (S_M) and the FFOV stimulus (S_F), shown in the figure. In most paradigms it is assumed that S_M will occur before S_F (the map is always viewed first). These are presented along a sequential time axis at the top and represent subsequent alternative viewings of the map and the FFOV (i.e., through visual scanning). At some point following the repeated observations of S_F and S_M, a response is given. In the experimental paradigm, this is often an explicit overt response (i.e. "same" vs. "different"). However, we realize in most closed-loop navigation tasks, it is simply a covert confirmation, followed by another iteration of S_M / S_F.

The key aspects of the model are the variables that influence the efficiency (time and accuracy) of the checking process. The model representation of this process is shown also on a time axis at the bottom of the figure. One may think of this representation as an evidence accumulation graph (Fitts, 1966; Pachella, 1974). The evidence represents the subjective belief or confidence that one of the two states of the world exists. Evidence for either sameness (i.e., a match between the map and FFOV) or difference (i.e., a mismatch) is represented from top to bottom. The strength of different sources of evidence, for sameness or difference, is represented vertically. The figure then is an adaptation of the random walk model of RT developed by Fitts (1966) and Pachella (1974) and applied to "same-different" judgment tasks by investigators such as Krueger (1978).

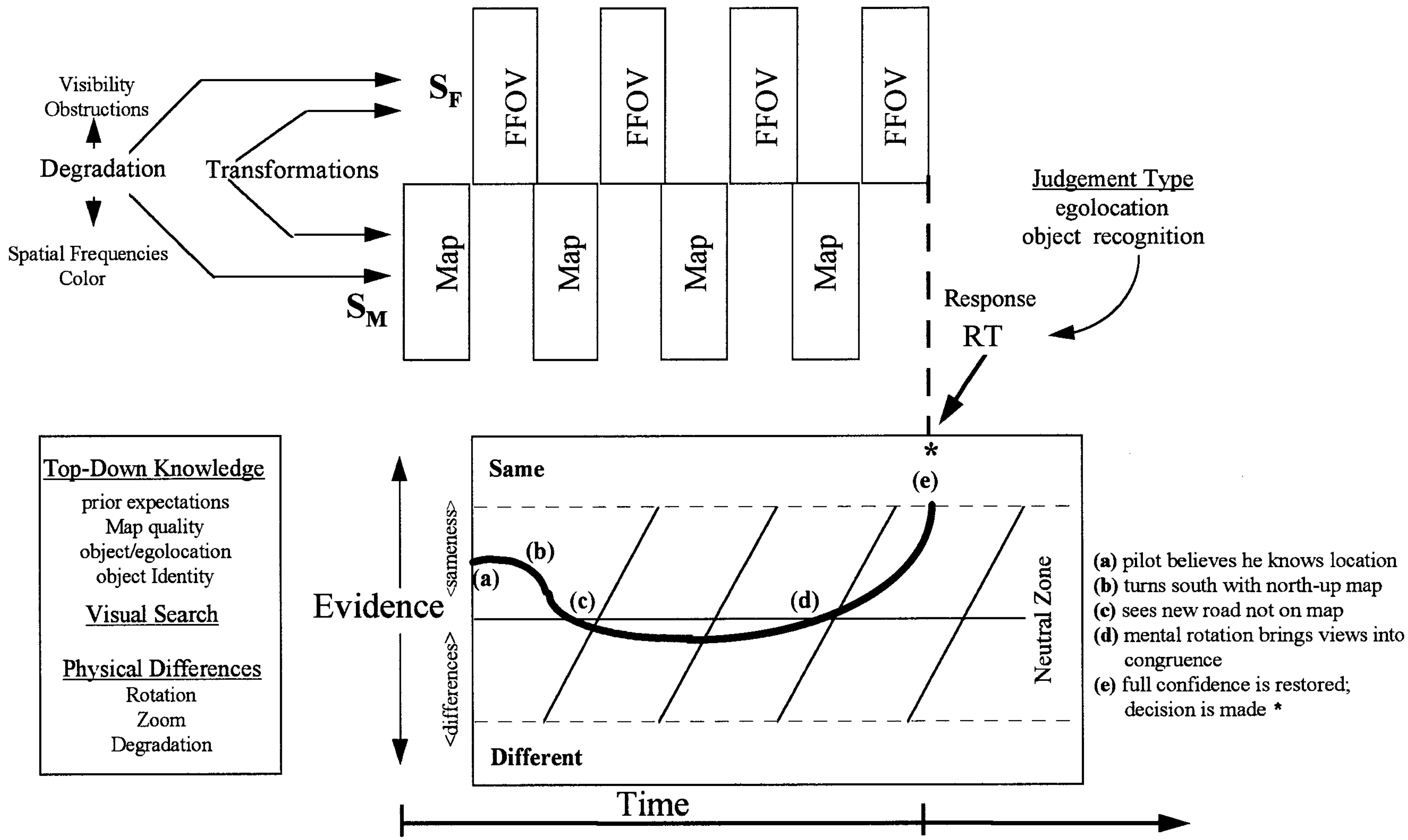


Figure 1.3-Navigational Checking Task Model

The model represents the process whereby as time passes, upon viewing iterations of S_M and S_F, various sources of evidence are accumulated to influence the confidence that either the two scenes depict the same or different physical location (i.e., region of geographical terrain). Different sources of information have different time courses by which they become available (or decline) and it is the NET effect of all these sources, depicted by the heavy black line, that determines the tendency toward a match or mismatch judgment (i.e., the degree of belief or confidence that the pilot is where she should be). Note that the evidence scale contains a "neutral zone" or region of uncertainty, in which the navigator is unwilling to commit to one decision (she is lost) or another (she knows where she is). When the evidence variable crosses out of the region of uncertainty (shown in the figure by *), a response is made, and the response time (RT) of the judgment can be measured. Depending upon the time criticality to commit to a decision, the boundaries of the neutral zone can be widened or narrowed.

A critical facet of the model concerns the factors that influence the evidence accumulation process, as these are applied to S_M or S_F, and as they affect the criterion setting process. These factors include judgment or task type, top-down, and bottom-up processing influences.

The task may vary along a dimension of whether the judgment is one of egolocation, or of target recognition. If an egolocation judgment is required, then the key facet is generally the collective evidence of all sources to confirm or disconfirm. Only one (of many) such sources might be whether a particular object in the scene (i.e., a building) is judged as the same between the map and FFOV. The navigator might also base this judgment on the triangulation of a set of two or more objects in the FFOV. Note that object comparison is often a subprocess on the way to egolocation confirmation (i.e. if the two representations of an object match, he is more confident he is where he thinks he is). However, in some circumstances object comparison may proceed even in the absence of precise egolocation knowledge. For example, the navigator may be certain that the two renderings of the object agree (the building he sees in the FFOV is the same as the "target" represented on the map), even if he is viewing the building from different azimuth or distance than he had expected on the map.

There are also processes that influence the top-down aspects of the matching process. That is, the expectancy the navigator has that he or she is lost or found. These influences are more directly exerted on the process model and are described as they affect the evidence accumulation graph.

Prior expectation and beliefs, refer to the a priori expectancies that one is "found", and therefore that one will obtain a match. This belief establishes the initial setting of the evidence variable, (Pachella, 1974; Fitts, 1966) in a direction that generally is biased toward a "same" judgment and its strength is represented by the distance from the center of the neutral zone. If one has been careful navigating all along, trusts the map, and has been encountering highly salient and discriminable landmarks, this variable should stay well above the center; and only minimum further display (i.e. bottom-up) evidence should be required to continue confirmation. However, the careful navigator should allow the influence of these prior beliefs to decline over time with each subsequent evidence sample, as new sources of perceptual evidence are interpreted. Otherwise the navigator can fall prey to the influences of the "confirmation bias" (Wason & Johnson-Laird, 1972; Antunano et al., 1989; Pick, Heinrichs, Montello, Smith, Sullivan & Thompson; 1995)

` Although judgment type and top-down processing do influence the navigational checking task, it is the bottom-up processes that this paper addresses. There are several classes of variables that influence bottom-up perceptual processing in the match process that are discussed. These are described in the following paragraphs.

a) **Evidence for sameness** will emerge from features of the two images whenever the navigator is actually on track and is characterized by the area of the graph in figure 1.3 above the center of the neutral zone. The speed with which this evidence emerges, however will vary as a function of the salience of the coinciding features in the two views, and with the extent of the necessary mental transformation (e.g. mental rotation) to bring them into congruence. These transformations will be discussed below.

b) **Evidence for difference**. This is shown by the area below the center of the neutral zone, and it may arise from one of two sources. First, any physical difference between the two renderings will produce a rapid and automatic "mismatch" registration even if both renderings depict the same scene (Krueger, 1978; Ericksen & O'Hara, 1982). This "mismatch" will certainly result from rotated images, etc. Its strength will decay over time as the necessary transformations are carried out (e.g., mental rotation to rotate or translate two images into congruent viewpoints) and hence, the congruent mental representation replaces the incongruent physical one. Second, any true differences in the scene, (i.e., if the pilot is lost or if features are viewed in the FFOV that are not depicted on the map) should emerge on "mismatch" trial, along roughly the same time

course as the similarity on “same” trials. However the aggregation of evidence for sameness and differences may follow slightly different time courses as Krueger (1978) has suggested.

Note that the physical difference detector may show somewhat different dynamics, depending upon top down knowledge. For example, if the navigator knows that the map may be drawn in error, this may serve to suppress the accumulation of evidence for physical differences as the navigator intentionally ignores some features of difference. If the navigator knows that the map will be viewed in an incongruous orientation, this knowledge too may serve to suppress evidence for physical differences. If the navigator knows in advance that the map’s color coding does not correspond to the coding in the real world, differences may be suppressed. This then is a second form of top-down processing; prior knowledge of map characteristics.

c) **Degradation** (or enhancement) may be applied to the map, if resolution is degraded at various spatial frequencies, if the map is presented in monochrome rather than color, or if certain map features are absent (e.g., rendering of vegetation, buildings, etc.). In operational environments, the “cause” of these degradations is typically the requirement to limit bandwidth of information transmission, or constraints on the speed of map image updating. Degradation can also be applied to the FFOV by viewing in foggy/hazy/low illumination conditions or by obstructions.

e) **Transformations** represent differences between the Map and FFOV in scale, azimuth rotation, and vertical rotation (i.e. dimensionality). These will be discussed extensively below.

f) **The visual search pattern** that a navigator uses while referencing a map and/or FFOV is critical to the understanding of what he or she is attending to while navigating, and how the pattern subsequently affects the efficiency of the checking process. Search, for example may be driven by top-down processes (examining regions of the field where one expects to find confirming evidence) or by bottom-up processes (attention is automatically drawn to a critical salient feature.)

In the particular instantiation of the model shown in figure 1.3 (page 7), the heavy black curve represents the accumulation of evidence by a pilot who has been carefully attending to wayfinding, and hence, initially believes that he is on the right course (i.e., is "found", **point a**). However having turned south, while using a north up map, he immediately notices an apparent discrepancy between the left/right position of images on the map, and those in the world, evidence for "difference", which pulls the evidence variable downward (**point b**). As the process of mental

rotation is carried out, the pilot also suddenly becomes aware of a new road in the FFOV that is not depicted on the map, further evidence for difference which contributes (**point c**), even as mental rotation is beginning to bring the two views into congruence. Once this congruence is attained, and progressively more features DO appear to match, greater confidence is gained that location is preserved, and the pilot can infer that the older map has simply not been updated to incorporate the newer road, hence allowing that aspect of "different" evidence to dissipate (**point d**). Eventually full confidence in location is restored (**point e**), and the process reiterates.

Within the context of the model, different environmental manipulations should have predictable effects on this process (e.g., degrading map imagery because of bandwidth limitations, presenting fixed maps, giving prior briefings of what to look for that will direct attention). Research using the navigational checking paradigm is limited at best and there is little knowledge of the strengths of these different influences, and therefore of how they play off against each other if one must be sacrificed in favor of another. The model then is an organizing framework that will help us keep track of these strengths. Literature will be reviewed to establish the cost of cognitive transformations most associated with the bottom-up processes of the navigational checking task, with the assumption that electronic map designs that can minimize the transformations that are costly to human performance will be worthwhile; but designs that minimize the cognitively easy transformations will require unnecessary financial costs.

Mental transformations

As stated earlier, the cognitive foundations of the navigational checking model can be found in the vast literature on object or scene comparison studies that utilize the “same/different” paradigm (Posner, 1978; Shepard & Metzlar, 1971). Underlying many of these paradigms is the idea that “sameness” is not necessarily physical identity; but rather identity after the physical properties of the image are transformed into congruence. In the same manner with navigational checking, sameness is not physical identity, but refers to scene identity after the cognitive transformations to align the two viewpoints have occurred.

Pilots engaged in navigational checking may encounter three types of geometric cognitive transformations when comparing the two images. Zooming may occur when the scale of the map is much larger than that of the FFOV, forcing the pilot to infer or interpolate features of the FFOV that are not necessarily on the map, or may be presented with such low resolution because of scale, that the object or feature may not be easily distinguishable. Such is typically the case as

most maps are drawn on a much larger scale than a pilot's FFOV. Azimuth angle rotations occur when the map and the FFOV are not oriented in the same direction. For example, this is the case when a pilot is flying with a north up map, yet is flying on a westerly heading. Either a physical transformation (turning the map) or a mental transformation (mental rotation) must occur for the two views to be congruent. Elevation angle rotations occur when the map and FFOV elevation angles are not the same. This is the case when flying with a 90° (top-down) map and an FFOV that is inherently 3-dimensional and something less than 90° (see figure 1.1). In addition, complexity influences transformations in two ways: 1) If maps are simplified, i.e. features of the world are deleted from the map, yet the FFOV depicts a very complex view with numerous roads, buildings, or geographic features, then there is a need to interpolate. In other words, if there are features in a pilot's FFOV that are not depicted on the map, a "filtering" of the additional FFOV features followed by a comparison of the common features would be necessary to determine position. 2) Although more complex images may inhibit the speed of transformation, the comparison "same" process my be easier with greater complexity because there are a greater number of congruent features. Each of these transformations is detailed below.

<u>Zooming</u>

Zooming occurs any time the scale of the map and the FFOV are not the same. Traditional aeronautical charts most used for visual navigation are made at a scale of 1 to 500,000. When a pilot is using this map for low altitude navigation, only a portion of the map (and hence, a small visual angle) actually corresponds with his present FFOV, occupying a much larger visual angle. By using only a small section of the map, the pilot is forced to mentally "zoom-in" on the target or reference area. Also due to the large scale, the map resolution is such that the pilot may be forced to interpolate information from the FFOV to the map which may not be depicted with as great a level of detail. This zooming-in task is also phase-of-flight dependent. At high altitudes, it is possible to have an FFOV scale and resolution matching the map closely; at lower altitudes, such a map cannot provide the detail necessary for accurate navigational checking. This "zooming-in" transformation has been documented to require additional time (Kosslyn, 1973) and may hinder a pilot's ability to make a same/different judgments.

Schreiber et. al (1995) examined the effects of map scale using a navigational checking paradigm. Their results indicated that larger scale maps are more useful when a pilot is trying to make a "same" judgments between two regions of space. Zooming (scale) had little effect with

perspective (3D) maps; but with planer (-90° or 2D) maps, large scale helped. Small scale maps were subject to what they referred to as the "keyhole" effect. This occurs when planar maps are at such a small scale that only a limited portion of the viewing area is available to extract information from and compare with the FFOV. Larger scale maps yield more features to compare with the FFOV. As an example, a pilot flying at cruise altitude using a larger scale map would have more information available; however, at a cost in the amount of resolution or detail. In contrast, at lower altitudes, a smaller scale map would be helpful in determining differences between specific features, such as roads, buildings lakes. In this case, having a smaller scale map with less overall information, but more detail in relation to the FFOV is beneficial. The conclusions of Schreiber, et.al. suggest that more research is necessary to accurately determine the effects of scaling or zooming on navigational checking.

<u>Azimuth rotation</u>

Several studies indicate there is a response time cost to making "same/different" judgments when two physically identical objects are presented at different angular rotations. This increase in response time is monotonic (usually linear) as the angle of rotation between the two objects is increased, and is generally been referred to as "mental rotation." This relationship was found by Cooper & Shephard (1973) who used letters to examine this rotational effect; Cooper & Shepard(1973) and Cooper & Podgorny (1976) used 2-dimensional objects; and Metzlar & Shephard(1974), Shephard & Metzlar(1971) and Steiger and Yuille (1983) used 3-dimensional objects . Results of the latter three studies indicate that 2-D objects are mentally rotated into congruence significantly faster than the 3-D objects (sometimes almost a ten fold reduction). Jolicoeur, Regehr, Smith & Smith (1985), suggest that from a theoretical standpoint, it seems reasonable that 2-D shapes would be rotated faster than 3-D shapes because rotation of three-dimensional objects entails that a portion of the object may be occluded by other parts of the object. They further state that the order of presentation of the stimuli (simultaneous or serial) plays a greater role in the response time increase with the rotation of the objects than with the mental rotation of shapes. In their study, they presented objects simultaneously and found that although there was a monotonic increase in response times with azimuth disparity, there was no difference between 2 and 3 dimensional objects for angular rotations between 0° and 60°. They did find however, that for larger angles, the speed of mental rotation was greater for 2-dimensional objects than for 3-dimensional objects.

In studies using map images and viewpoint comparisons, researchers have examined the costs of viewpoint disparity also in terms of mental rotation; however, here the linearity of response times is not always obtained. Eley (1993) had subjects look at two-dimensional topographic maps and compare them to three-dimensional land surface drawings at varying azimuth angles. Not surprisingly, he found that azimuth disparities of zero degrees yielded lowest response times. Increasing the azimuth angle disparity also yielded progressively larger response times. Goldberg, Maceachren, and Korval (1992) had subjects compare three-dimensional topographic maps of a simple three mountain region presented from different azimuth perspectives. They too found that higher angular deviations yielded higher response times in a near linear relationship. However, they found that the lowest response times were actually, at -120° azimuth not at an expected 0°. The authors explanation for this phenomena was that subjects pre-rotated the first (standard) view by -120° to prepare for the second (presented) view. They further suggest that the reason for this initial pre-rotation rotation was because the standard map was then less obscured at this angle than when it was actually presented.

In two experiments more veritable to the air navigation task, Aretz and Wickens (1992) asked subjects to compare a north up map to a map that could vary in azimuth angle anywhere from 0° to 315°. In the first experiment, they found that response times were fastest at 0° angular disparity, increased non-monotonically up to 180°, and then dropped off uniformly as the deviation increased above 180°. They found similar results in experiment two; however, response time was linear up to 90° disparity, increased non-linearly up to 180°, then dropped off uniformly again as disparity increased above 180°. Wickens (in press) summarizes these experiments and distinguishes the non-linear latency effect of azimuth disparity from the linear effects of mental rotation and refers to the former a "symbolic transformation" or reversal mapping. He suggests that one would find non-linear costs with azimuth angle disparity; disproportionately small, when rotation is less than 90° and disproportionately, and larger when it is greater than 90°, at which time mappings must be reversed. In a study that specifically incorporated the navigational checking paradigm, Schreiber et. al (1995), also investigated the effects of azimuth deviations. In their study, subjects viewed a realistic computer generated world, consisting of roads, bridges, buildings, runways, and rivers. The map and FFOV both generated on the same IRIS display, deviated in azimuth angles ranging from 0 to 90°. They found monotonic, generally linear increases in response times as angle disparity was increased.

Conclusions from the previous research tends to support the notion that for simple letter, shape or object comparison studies, the response time costs of azimuth angle incongruity are the result of an internal linear mental rotation, whereas with complex stimuli, as in the viewpoint and scene comparison and navigational checking studies, the transformation process is perhaps not quite as simple. It may include mental (viewpoint) rotation, symbolic reversals and, as we see in the following section, possibly image distortion effects. Although applied research has been limited with respect to the navigational checking paradigm, there is ample evidence in the basic studies using object comparisons and the few viewpoint comparison studies using more realistic navigational images, to highlight the robustness of the cognitive costs of azimuth angle disparity and mental rotation.

Elevation angle rotation

Differences in elevation angles between a map and a pilot's FFOV also reduce efficiency in 3-dimensional image comparisons. Eley(1988) and Aretz and Wickens (1992) establish the cost of "envisioning" two-dimensional planar maps as three-dimensional representations. Because angular deviations are considered in the comparison, this effect is sometimes referred to as mental rotation as well (Aretz & Wickens, 1992). Schreiber et al., (1995) call it a "special instance of elevation angle mental rotation." Although Aretz & Wickens found that the time costs associated with a 90° vertical rotation were the same as a 90° azimuth rotation, results from more recent research, including Schreiber et al., (1995) clearly illustrates that the pattern of response time costs with elevation angle deviations departs from the patterns normally associated with mental rotation, as the former are clearly non-linear, suggesting a more complex process than simple mental (viewpoint) rotation.

For example, Goldberg, Maeacheren, and Korval (1992) had subjects compare two different 3-dimensional topographic maps that varied in elevation angles. In agreement with previous studies, they found that response times were fastest at 0° disparity; however, response times increased non-linearly with increasing angular disparity, such that small disparities had minimal effect. Again, using the navigational checking paradigm, Wickens et al., (1994) and. Schreiber et al., (1995) replicated this pattern of data. In the former experiment, subjects compared simple geometric objects presented at varying elevation angles, whereas in the latter study, subjects compared more realistic computer generated navigational images presented at

varying elevation angles. Results of both studies indicated nonlinear trends as angular deviation increased.

Each of these studies also indicate that there is apparently a greater cost for a given disparity at lower elevation angles (see figure 1.1, page 3). This finding, combined with the non-linear trend suggested by the previous examples, indicates that the response time costs of angular deviations are dependent not on the magnitude of the angular deviation, as with mental rotation, but on a more complex process, which calls for an elaboration of the navigational checking model. A description of this process is detailed below and is a major focus of the present research.

Model of elevation angle effects

Modeling the effects of elevation angle disparity depends, in part on three aspects; 1)what the pilot attends to, 2) how disparity is measured and 3) past familiarity.

The question of what pilots attend to is crucial to the navigational checking task. In other words, what features of the FFOV is the pilot looking at to compare with the map? Or conversely, what features on a map are attended to prior to referencing the FFOV. As stated earlier, the pilot's attention is affected by both top-down (expectancy) and bottom-up (salience of features) processes. Wickens et al., (1994) suggest that when navigating, aviators use more horizontal information than vertical information to triangulate and determine their position. This implies that an aviator would attend to features of a more horizontal nature such as the shape of road intersections, the relative position of a group of hills or mountains, or the displacement of buildings, rather than the vertical (height of such objects). Given the relative importance of horizontal information, it is meaningful to consider how the amount of horizontal information resolution changes, as viewpoint or elevation angles change.

For the purposes of this paper, the resolution of an object depicted on the display can be defined as the amount of display pixels per unit of true area. Resolution is thus inversely related to compression. Objects displayed at different elevation angles would have different amounts of both horizontal and vertical resolution available as a function of the varying amounts of pixels filled in an object representation. Although this is defined in terms of a computer generated "world", there is a definite corollary to the "real" world as the resolution of actual images, now represented by visual angle, rather than by pixels, never the less follows the same function as the image is rotated vertically. Figure 1.4 represents how the resolution of objects changes as elevation angles change.

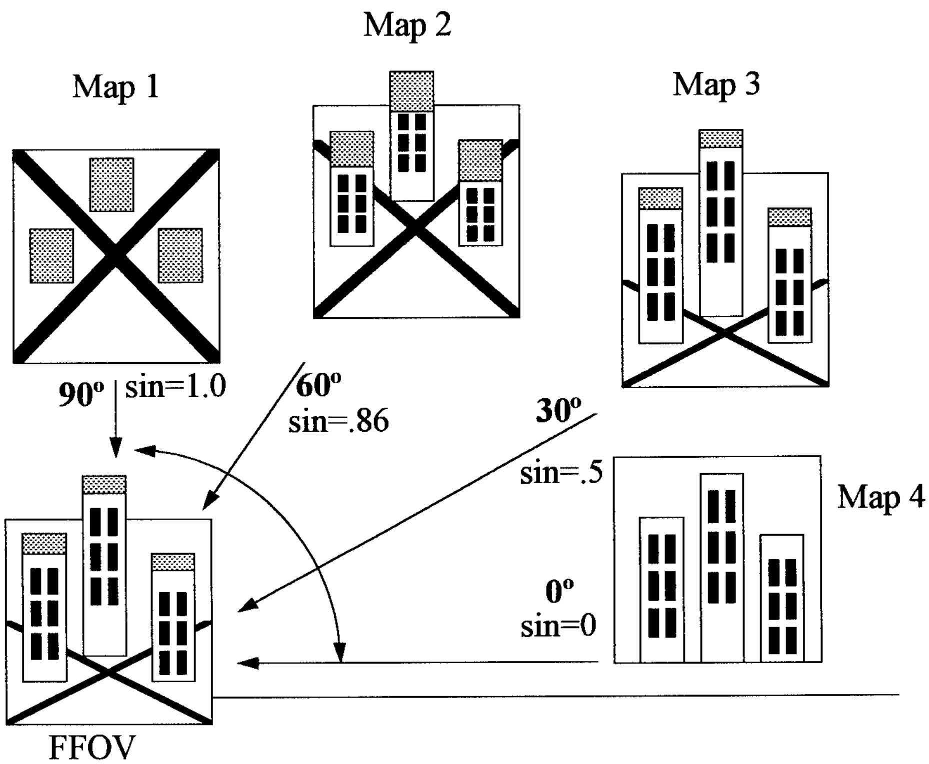


Figure 1.4: Representation of changes in resolution of features in a scene depicted on a map at several different elevation angles

The figure depicts a single scene (lower left) represented by four different viewpoints. These viewpoints depicted by the arrows, are each associated with the corresponding map image. As the map viewpoints differ, the size and shapes of the features also change. With a 90° map, the roads are relatively wide and intersect at right angles, and buildings are simple squares as the view is from directly above (Map 1). As the viewing elevation angle is decreased, the roads become thinner and intersect at a more oblique angle, while the buildings begin to display more vertical information as the height of the buildings and windows are exposed (Map 2 and 3). The road then is completely out of view and the relative lateral spacing of the buildings are unknown when viewed from an elevation angle of 0° (Map 4). As indicated by the figure, the resolution of horizontal information available and the changes in physical image at each elevation angle can be represented as a function of the sin of this angle.

Figure 1.5 graphically illustrates the nature of the changes in both horizontal and vertical resolution gained or lost as an image is rotated on the vertical plane (elevation angle disparity), as a percentage of total resolution available on a given plane.

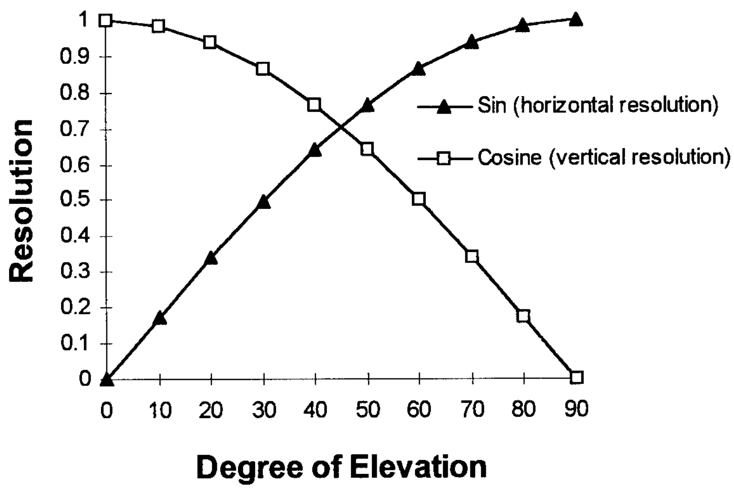


Figure 1.5: Horizontal and vertical resolution in terms of sin and cosine functions

The sin curve represents the horizontal resolution of the images projected against the 2-D image plane (e.g. shape of road intersections and lateral displacement of buildings or hills). A 90° map, yields a sin equal to 1, meaning that 100% of the horizontal resolution is available for viewing. Likewise, the sin of 0° is zero, yielding no horizontal resolution at all. Comparing a 90° map (sin=1) to a 60° FFOV (sin=.866) yields a .134 or 13.4% loss in horizontal resolution $|\sin(Map) - \sin(FFOV)|$ produced by the 30° disparity in elevation angle from a 90° map. In contrast, a 45° map angle (sin=.707) and a 15° FFOV(sin=.258) yields a higher resolution loss of .448 or 44.8% for the same 30° disparity. It is apparent from this example, that changes of viewpoint at lower elevation angles (lower altitudes) yield larger changes in resolution, even though the angular displacement (30°) is the same as at the higher elevation angle comparisons.

In a similar manner, the cosine function represents the amount of vertical resolution available (e.g. depiction of differences in altitude). In an analogous comparison of viewing angles, it is easy to see how vertical resolution is affected more when angular displacement is at higher viewing elevation angles.

As indicated by the two functions depicted in figure 1.5, a viewing angle of 45° provides the best combined resolution for both vertical and horizontal information. As this could be predicted as an "optimum" viewing angle, an argument might be made to have electronic maps designed for 45° viewing angles. Evidence to support this prediction of 45° as optimal is found in

several recent studies. Green and Williams (1992) had subjects seated in an automobile mockup and were shown slides of intersections taken from the automobile FFOV. Subjects were then asked to make same/different judgments based upon slides generated by a computerized navigational display. This display presented images from elevation angles of 0° (forward "drivers eye view), 90° (plan view), or from an aerial view with the elevation angle (stated to be somewhere around 45°). Results indicated that the aerial view (around 45°) yielded the highest accuracy and lowest response times. In two studies that did not involve image comparisons, Ellis, Kim, Tyler, McGreevy, & Stark (1985) and Kim, Ellis, Tyler, Hannaford, & Stark (1987) had subjects perform a three-dimensional tracking task in varying elevation angle conditions (from 0° to 90°) Results from these two studies indicated that the tracking performance was best at elevation angles of 45°. In a related study, Yeh and Silverstein (1992) had subjects make altitude and depth judgments between a referent and target object at three different elevation angles 15°, 45°, and 90°. They found that at 15°, depth judgments were the most difficult, yet altitude judgments were the fastest. This could be predicted from the sin function of figure 1.5. Low elevation angles retain little resolution in horizontal judgments.

Conclusions from the above mentioned studies would suggest that a 45° viewing angle is optimal. However, in each of these studies horizontal and vertical information was equally important in performing the particular task. Since relative depth/altitude judgment and tracking tasks require equal processing of both vertical and horizontal dimensions, it is logical to assume that 45° would be optimal. Given the greater importance of lateral or horizontal information over vertical information in many aspects of airborne navigation, one could predict that the sin function of the elevation angle is more appropriate than the cosine function when considering the resolution of information that is important to the task of navigational checking. Accordingly, a viewing angle greater than 45° should support better performance.

Indeed, the sin function curve, which characterizes the manner in which horizontal resolution and shapes change as a function of the sin angle, appears to account for prior research producing the non-linear response time functions of angular disparity. The data for these two studies (Schreiber et al., experiment 1 (1995), and Goldberg et al., 1992) are reproduced in figure 1.6.

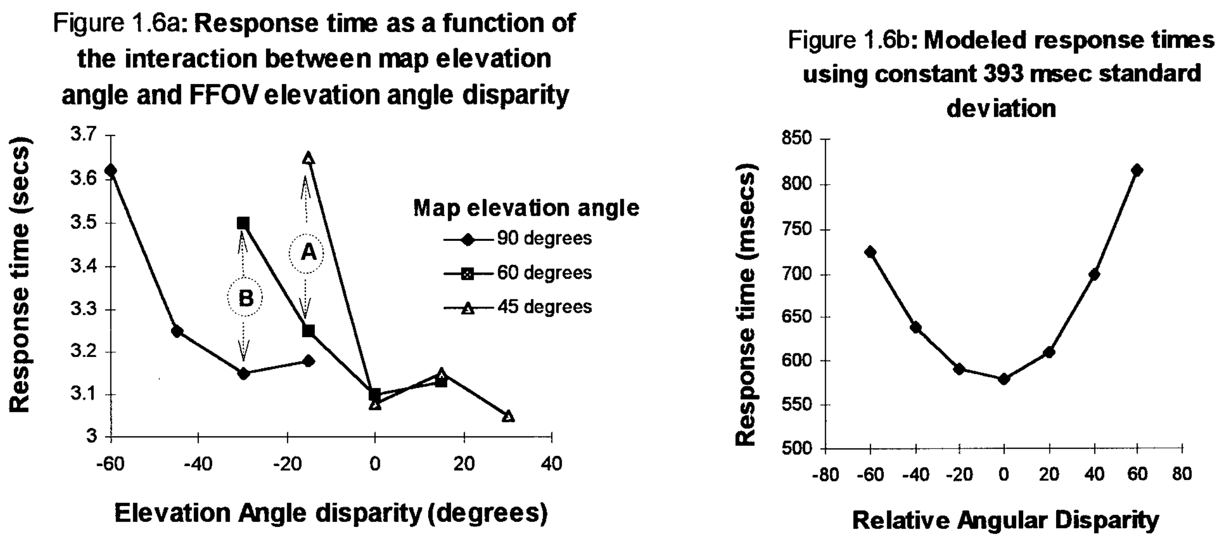


Figure 1.6: Schreiber et al., (1995) (1.6a) and Goldberg et al., (1992) (1.6b). Response times as a function of angular disparity

Both of these data sets depict distinctly non-linear functions of elevation angle disparity, suggesting that this transformation from one viewing angle to another is not due simply to mentally rotating the images into congruence at a constant speed, or rotating the imagined viewpoint at a constant velocity, as a linear function would suggest, but rather by a transformation process that involves the sin trigonometric function. Re-examining the data of Schreiber et al., and Goldberg et al., reveals that response times may in fact, be linear when plotted as a function of the differences in the sin of the viewing angles. Using the Schreiber et al., data, refer to figures 1.7a and 1.7b.

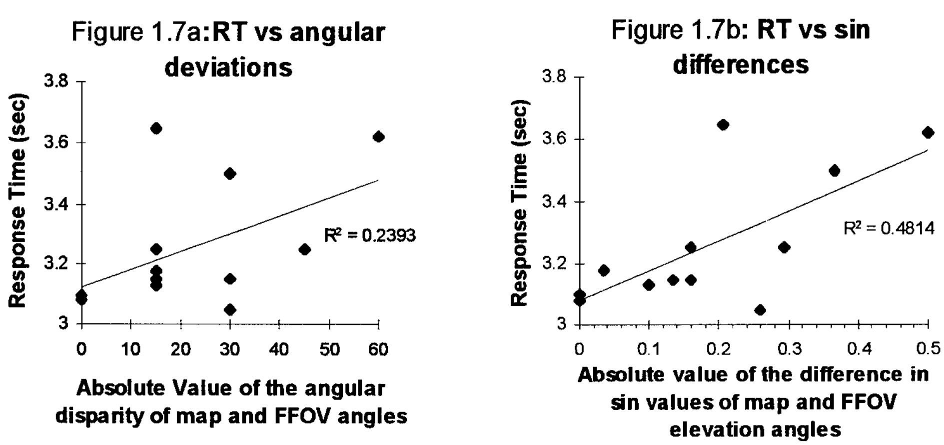


Figure 1.7: Schreiber et al., (1995) data recalculated comparing response time as a function of map and elevation angular disparity (1.7a) and sin disparity of the angles (1.7b)

Figure 1.7a depicts response time as a function of angular deviations, whereas figure 1.7b depicts response time as a function of the difference in the sin of the viewing angles. Also plotted are linear regression lines and R^2 (explained variance). Comparing the angular deviation functions in the two plots, reveals almost 25% more of the variance for the data is accounted for in the "sin-sin transformation" function. Because of the way Goldberg et al., present their data and the lack of primary data available to re-evaluate, a similar comparison is not possible; however, given the curvilinear shape of their modeled function shown in figure 1.6b, it expected that a sin-sin transformation of the angular disparity would also reveal additional variance accounted for.

The assumption is made that the image transformation time occurs equally between map and FFOV regardless of which one depicts the lower or higher elevation angle. For example, transformations of a 30° FFOV elevation angle compared to a 60° map elevation angle would produce the same response time as if the two angles were reversed, hence the absolute value of the sin difference is plotted against response time. Thus, data from both Goldberg and Schreiber appear to be better explained by assuming RT=K(constant) + $B^*\left|\sin(Map\varphi)-\sin(FFOV\lambda)\right|$ than by RT =K(constant) + $B^*\left|(Map\varphi)-(FFOV\lambda)\right|$).

A second implication of this sin-sin transformation is that equal elevation angle disparity differences at lower FFOV's (lower altitudes) will create larger image disparities and therefore impose greater costs, an effect we noted in figure 1.4. Also referring to figure 1.6a, it is interesting to note the comparison of the distances represented by points "A" and "B". Point "A" represents the latency difference between two map angles (45° and 60°) at a common FFOV angular disparity. One can see that although the angular disparity is -15° for both map angles, the latency for the 60° map angle is approximately 0.4 seconds faster than the latency for the 45° map. A similar result is found at point "B". Here the latency difference between map angles of 60° and 90° is also approximately 0.4 seconds at a common angular disparity of -30°. Implications of the above if confirmed would suggest that dynamically updated maps matching the momentary slant angle of the FFOV would be preferred at lower altitudes. If static maps are to be used, then the optimum elevation angle will be determined by the importance of the lateral variance and by the altitude being flown on the mission. Lower FFOV angles would favor lower map angles (Schreiber, Wickens, Renner, & Alton, 1996). Although Schreiber et. al draw these

conclusions from the three experiments they conducted using incrementally more complex stimuli, the experiments were limited in the numbers of map angles that were compared, hence further research is reported here using scenes more realistic to the navigational task and using a wider range of map angle comparisons.

Complexity

There is a large number of possible definitions or features that can characterize image complexity (Dember & Warm, 1979); for example: information content, symmetry, heterogeneity (Tullis, 1983). Given the robust finding in visual search research that increasing the number of elements in a search field prolongs search (e.g. Drury & Clement, 1978), in the current experiment we chose to operationally define complexity in terms of the amount of information or the number of visual elements that is available on the two images to be compared. For example, an image that depicts an urban scene with roads, buildings and numerous other manmade landmarks, would be considered more complex than an image that depicts flat farmland or a desert.

The effect of image complexity is itself complex with many uncertainties; however two effects are well established: a) more complex images require longer to search for critical features (Drury & Clement, 1978; Mocharnuk, 1978), and b) more complex images appear to take longer to transform (e.g., through mental rotation; Cooper and Podgorny, 1976; Aretz and Wickens, 1992; Silverman 1974; Yuille and Steiger, 1982). However, how image complexity affects same/different judgment tasks is less clear and might be likely to interact with response type and with subject search strategy. For example, consider figure 1.8 which depicts schematic image pairs to be compared (image 1-image 2.) In a very complex scene, there might be a large number of features that are different (if incongruent), and therefore RT to say "different" would be faster than if the images were simpler (case 1). Correspondingly, with a serial search pattern, it may be harder (slower) to say "same" with more complex stimuli since the "search" for sameness will need to be serial and exhaustive (case 2). But if sameness is not judged by a serial search, but by a global holistic check, complex stimuli such as that shown in the bottom row of case 2 may elicit a more rapid "same" response. Finally, if the difference is subtle (i.e., only a single feature), it will be more difficult to detect with complex stimuli (case 3).

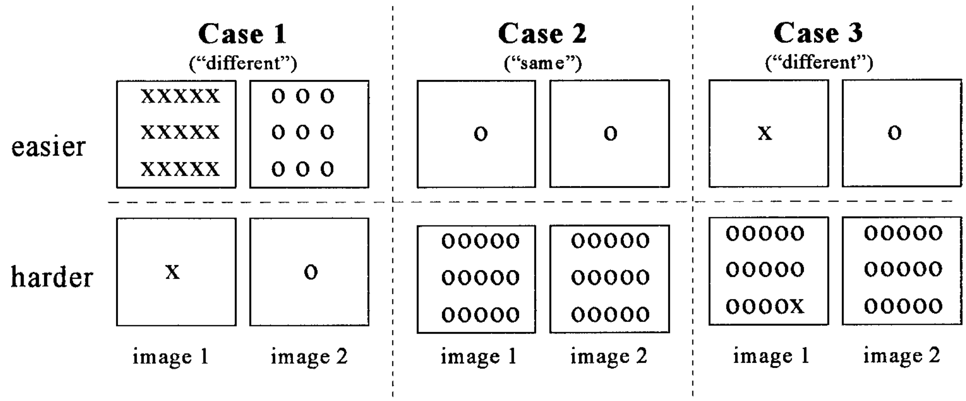


Figure 1.8: complex vs. simple stimuli comparisons

Results from the literature are ambiguous. Consistent with case 3, Tversky (1977) suggests that when making "different" judgments, response times are not based on the total number of features, but on the ratio of shared features to different features. Accordingly, discriminibility difficulties in response time tasks can be reduced by deleting shared and redundant features where possible. In navigational checking, reducing the number of features of an FFOV is not possible. Map simplification (reducing numbers of features) may in fact improve discriminibility provided the information remaining is sufficient to maintain efficient navigation checking. In the present study, the assumption is that all features available in the FFOV are available on the map, therefore, changes in the number of common features that are shared between the map and FFOV is not manipulated.

But Tversky's theory says little about judgments of "sameness", which are the most prevalent in the navigational checking task. Assuming a serial type search pattern and consistent with case 3 again, other studies that have examined same/different tasks with stimuli of varying complexity found that more complex images elicited slower "same" response times than simpler images (Cooper and Podgorny, 1976; Aretz and Wickens, 1992; Silverman, 1974). It is also interesting to point out that in some research, image complexity appears to interact with the effects of disparity in both azimuth and elevation angles. For example, Hall & Friedman (1994) and Yuille and Steiger (1982) found that higher levels of complexity tended to amplify the costs of mental rotation. It should also be noted that the increasing complexity of the experimental stimuli across the three studies described by Schreiber et al. (1996), produced a concomitant increase in response time, although other variables differed between experiments that prevent this comparison from being a "pure" one. Nevertheless, it is probable that the more dominant effect

of complexity will be that of search, for disconfirming (mismatching) evidence, which will be a mechanism predicted to increase response time with increasing complexity. We examine this hypothesis in the present experiment.

Feature type

The question of what features a pilot is drawn to or attends to during navigational checking is critical to the understanding the visual search patterns of one engaged in this task. By drawing a dichotomous distinction between two types of features, man-made (cultural) vs. natural features, researchers can determine which features are most relevant and thereby highlight them or make them more salient in the design of maps. Literature is scarce in this area, as most research has been done with how humans navigate in built environments without much attention to naturalistic settings. However, conclusion from the few available studies imply that images depicting primarily a naturalistic setting with no manmade features take longer to identify than scenes that depict man-made or cultural features (Whitaker & Cuqlock-Knopp, 1995). These authors suggest that there are visual cues such as straight lines and right angles found in man-made settings that make features easier to distinguish and consequently allows easier navigation than in more naturalistic environments. Finally, a distinction made by Biederman & Gerhardstein (1993) between viewpoint dependent and viewpoint invariant features may be relevant to the contrast. Viewpoint invariant features are more likely to be cultural or man-made features with distinct recognizable shapes from any viewpoint (e.g., a house), and their use in scene perception should be less disrupted by changes in viewpoint (e.g., differences in map elevation angle), than viewpoint dependent (i.e. natural) features. This hypothesis was confirmed in object recognition and comparison tasks by Wiebe and Converse (1996). Whether it generalizes to scene judgments will be a question asked in the current research.

Present research

In summary, the literature has shown that when attempting to establish whether or not two objects or images are congruent, there is a cost in efficiency (response time and accuracy) as the physical difference between the two increases. This degradation in efficiency is directly related to the amount and type of cognitive transformations necessary to bring the two into congruence to determine if in fact they are the "same" or "different". This finding has direct implications to the ideas fundamental to the task of air navigation and to a cognitive model of navigational checking. Although many effects have been modeled with varying degrees of consistency, azimuth angle

effects have been perhaps the most consistent and replicated (Cooper & Shepard, 1973; Cooper & Podgorny, 1976; Metzlar & Shephard, 1974; Shephard & Metzlar, 1971; Steiger and Yuille, 1983; Goldberg, Maceachren, and Korval, 1992; Eley, 1993 Aretz and Wickens, 1991). Data to support similar transformations along other axes within this model are scarce, particularly with regard to elevation angle disparity and image complexity. Yet both of these issues have tremendous impact on the design of electronic maps. Therefore the present experiment will attempt to reach some consensus as to the effect of these two variables, and recommendations to the design of electronic maps will be made as a result.

Results from the study by Goldberg et al., (1992) suggest a non-linear effect of elevation angle disparity; however, the computer generated scenes were simple topographic renderings that depicted only three peaks. Using the navigational checking paradigm, results from the experiment performed by Wickens et al., (1994) and the two performed by Schreiber et al., (1995) also revealed a similar, non-linear effect of elevation angle disparity using progressively more realistic and complex images. However, each study was limited in its levels of independent variables. In the first experiment by Wickens et al., (1994), although several different elevation angle disparities were considered, the images compared were simple polygon volumes. In the first experiment by Schreiber et al., (1995) both images that were compared were of computerized renderings of air navigational scenes generated by a Silicon Graphics IRIS computer. Although the imagery was more realistic to the navigational task, only 3 different FFOV viewing angles were considered (45°, 60°, 90°), leaving out low-viewing angles critical to navigation at low altitudes. Finally, in the second experiment by Schreiber, et. al (1995)., an Evans and Sutherland computer was used to generate a more realistic FFOV than any of the previous experiments, while the map view was generated on the IRIS computer. This experiment too added a measure of realism to the investigation of navigational checking; however the experiment, only considered 45° and 90° map angles and hence the degree of non-linearity could not be established. Results from each of these studies contribute greatly to the understanding of the modeled effects of elevation angle disparity, however, the data are inadequate to model the effects of the full range of elevation angles possible combined with realistic navigational scenes. There is also a need to explore in a more systematic way the non-linearity of the elevation angle effects. This effect may in fact be linear when angular disparity is considered as a function of the difference in the sin of the angles (sin-sin). Hence, the proposed experiment will use the same realistic image generating

computers used in the second experiment of Schreiber et al., (1995); combined with a careful examination of a several different FFOV and map viewing angles, simulating both high and low altitude flight. Although results from this experiment should replicate the findings of the previous research, it would fill in the gaps not formerly investigated.

Similarly, the issue of complexity within the navigational checking task needs a more thorough examination. Aretz & Wickens (1992) and Silverman (1974) suggest that as complexity is increased, subjects require more time for judgments. There is also some evidence to indicate that there is an interaction between image complexity and mental rotation. That is, the costs of mental rotation are increased by higher levels of complexity (Hall & Friedman, 1994; Yuille and Steiger, 1982; Aretz & Wickens, 1992). Although the present paper argues that elevation angle effects may not in fact be "mental rotation" it could nevertheless be predicted that higher levels of complexity would amplify the effects of elevation angle disparity as the physical differences between the two compared images increases. The present experiment will examine level of complexity and its interaction with elevation angle disparity

Finally, the data reviewed suggest that images that depict primarily a naturalistic setting with no manmade features, may take longer to identify than scenes that depict man-made or cultural features. The present research will compare the efficiency of navigational checking with scenes containing more cultural or man-made features with those in more naturalistic settings. In order to investigate these issues, an experimental design protocol similar to those employed in previous navigational checking research will be followed.

Methods

Subjects

Twenty-six subjects ranging from eighteen to thirty-one years of age (mean=20.3) were recruited from two different instrument flight classes taught by the Institute of Aviation at the University of Illinois. All subjects had only a private pilot rating with a range of flight time from sixty to two hundred hours (mean=97.4). All subjects received the same instructions (Appendix A) and were paid $5 per hour for their participation. Subjects were paid an additional $1 bonus as an incentive if they achieved at least 90% accuracy. Twelve subjects (46%) were paid this bonus.

Apparatus and materials

An Evans & Sutherland SPX500 generated the FFOV and projected it onto a 7' by 10' projection screen. A Silicon Graphics IRIS computer with a sixteen inch diagonal monitor was used to present the electronic map, as well as to record response times and accuracies. Subjects sat in a chair approximately 32" from the IRIS computer monitor (approximately 26° visual angle to center of screen) and 11 feet from the projector screen. To make a response, subjects used a computer flight simulator joystick in their right hand, pressing either a button to indicate "different", or squeezing the trigger to indicate "same".

The task

During each trial, subjects were presented with static images of scenes from a digitized "world" generated by both the Silicon Graphics and the Evans & Sutherland computers. The "world" consisted of a 15 square mile area depicting roads, bridges, towns, mountains and rivers as well as other natural and man-made features and structures (Williams, Hutchinson & Wickens, 1996). An IRIS representation of this "world' is depicted in figure 2.1. Although both the map and FFOV were computer generated, the Evans & Sutherland display (figure 2.2) offers digitized scenery that is significantly more realistic and detailed than the Silicon Graphic Iris display (figure 2.3). The subject's task was to compare the two computer generated images and determine if they depicted the same geographic location. "Different" alterations were created by the experimenter and were generated by changing the appearance, shape, orientation or existence of a few features located toward the center of each scene. Differences could be found with roads, bridges and buildings, or with rivers, mountain ranges, or plateaus. The images may have looked identical except for one or two changes or deletions. A "different" representation of the scene is

found in figure 2.4 (note the shape of the river bend). The map was always presented in a "track-up" position, yielding no azimuth differences between the map and the world.

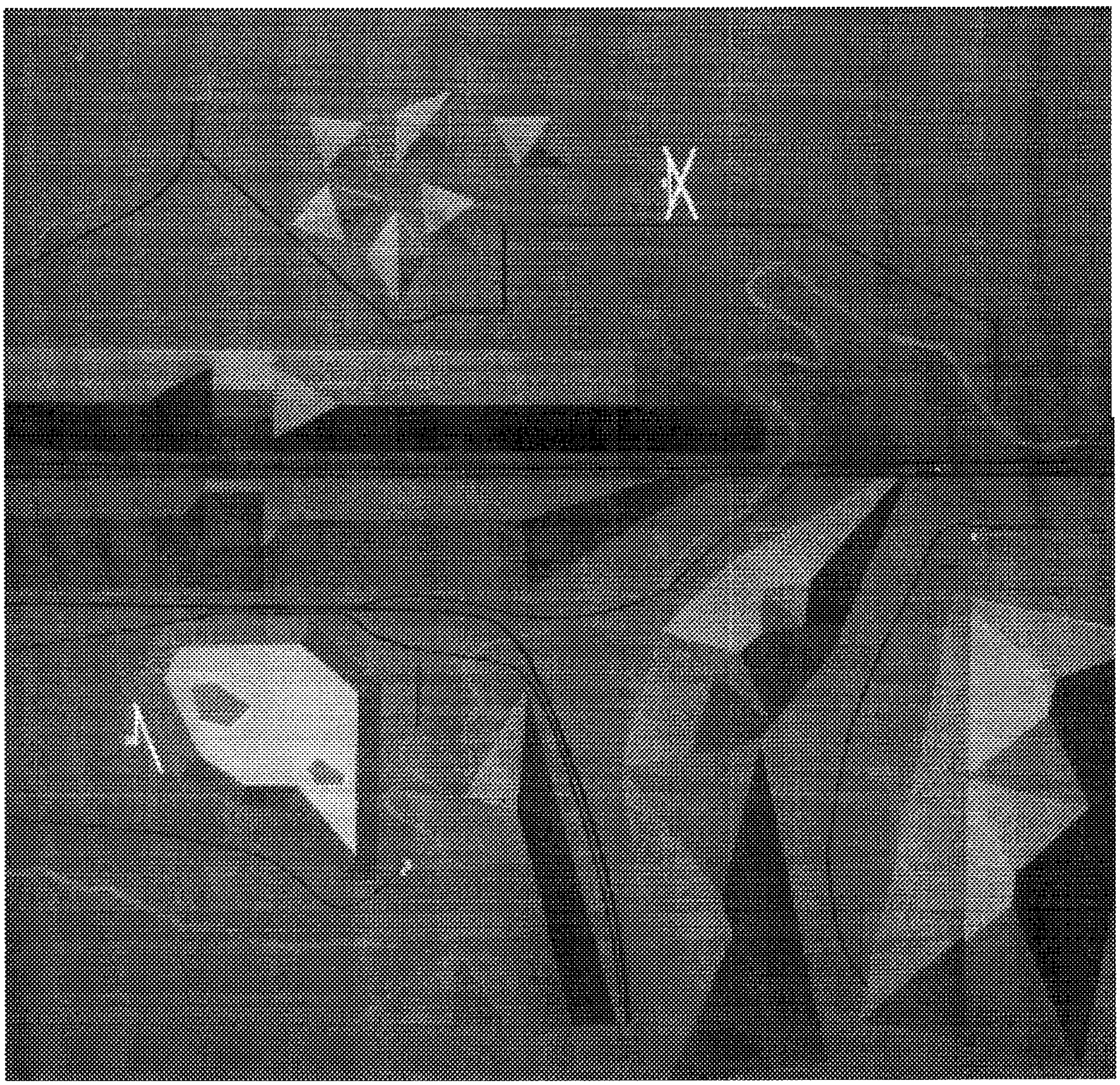


Figure 2.1 IRIS representation of the experimental"world"

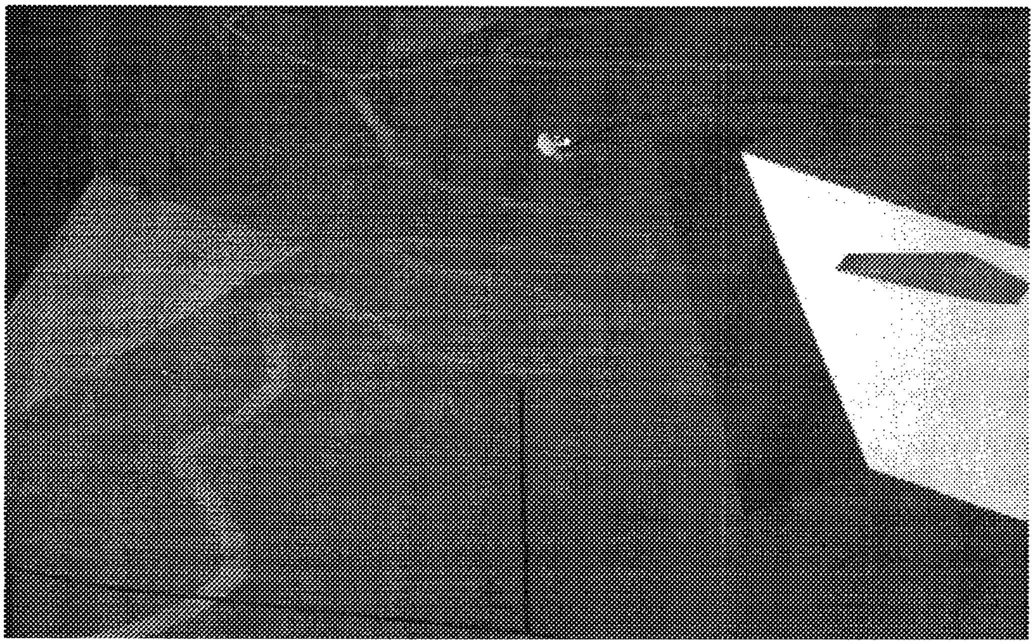


Figure 2.2: IRIS generated representation of a 30° "map" elevation angle

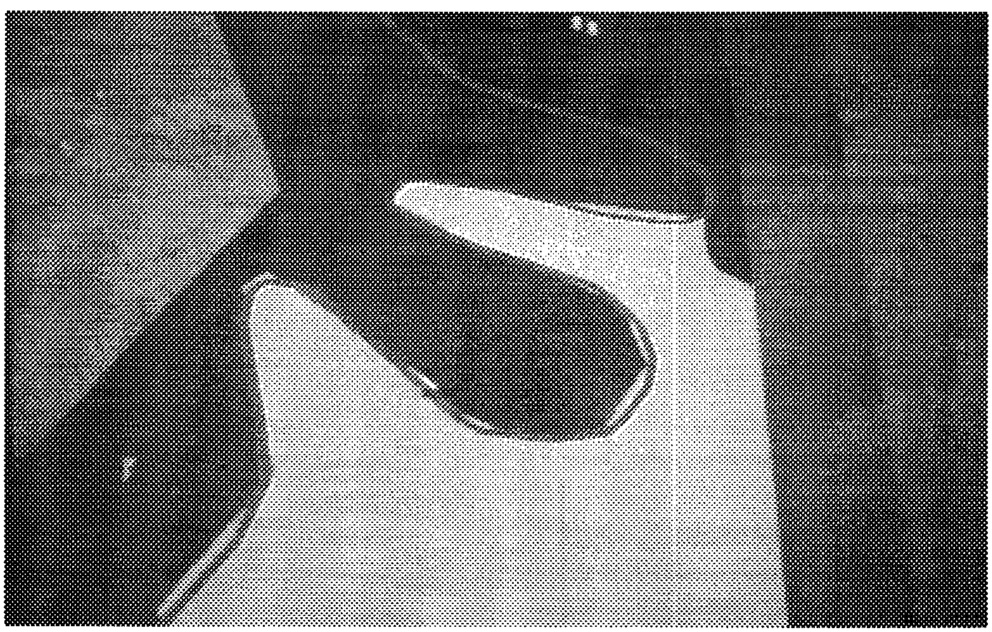


Figure 2.3: Evans and Sutherland generated representation of a 60° "FFOV" elevation angle

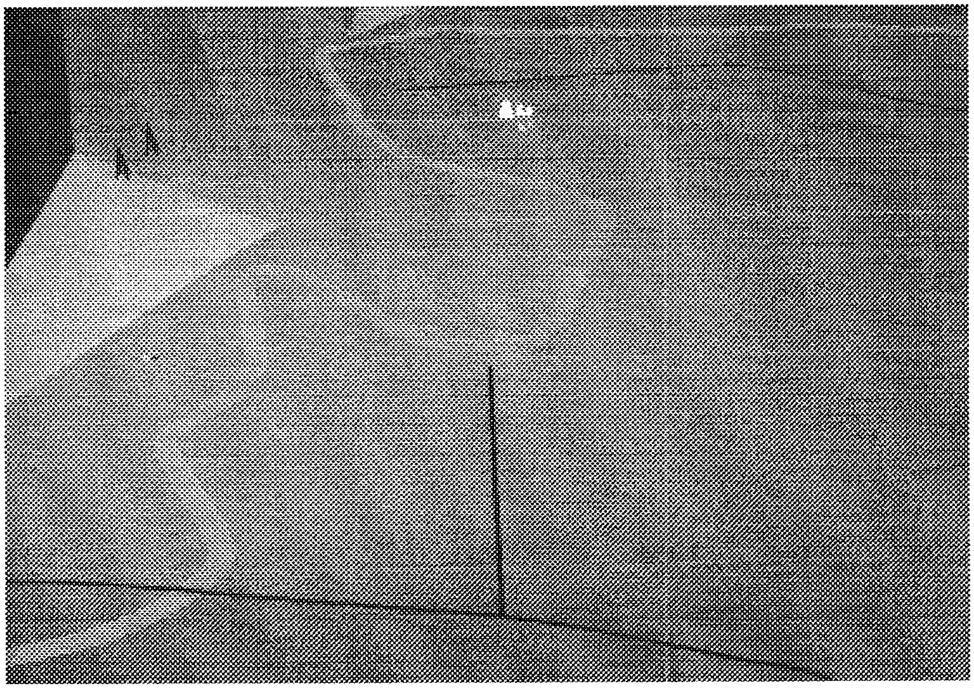


Figure 2.4: IRIS generated "different" representation of a 30° "map" elevation angle.

Experimental design

The scenes that were presented to the subjects were varied on three parameters (independent variables) in a completely within subjects design 1)The sin deviation of the map and FFOV elevation angles (sin-sin) 2) Complexity and 3) Feature type. Each of these variables is detailed below:

1)Sin deviation (sixteen levels)-This was calculated by taking the absolute value of the difference between the sin of the map elevation angle and sin of the FFOV elevation angle. Six different map elevation angles (15°,30°,45°,60°,75°,90°) and five different FFOV elevation angles (15°,30°,45°,60°,75°) were used. The 90° FFOV is excluded from this experiment due to aircraft design features as it is unrealistic that a navigator would be looking straight down to determine geographic orientation. Although there are thirty possible combinations of angular deviations, only sixteen possible sin deviations exist, hence there were sixteen levels of this variable (see table 2.1).

FFOV angle	Map angle	sin deviation of angles
both must be same		0
90,75	75,90	0.034
75,60	60,75	0.099
90,60	60,90	0.134
60,45	45,60	0.159
45,30	30,45	0.207
30,15	15,30	0.241
75,45	45,75	0.259
90,45	45,90	0.293
60,30	30,60	0.366
45,15	15,45	0.448
75,30	30,75	0.466
90,30	30,90	0.500
60,15	15,60	0.607
75,15	15,75	0.707
90,15	15,90	0.741

Table 2.1a

		FFOV angles				
		15	**30**	**45**	**60**	**75**
Map Angles	**15**	0	0.241	0.448	0.607	0.707
	30	0.241	0	0.207	0.366	0.466
	45	0.448	0.207	0	0.159	0.259
	60	0.607	0.366	0.159	0	0.099
	75	0.707	0.466	0.259	0.099	0
	90	0.741	0.5	0.293	0.134	0.034

Table 2.1b

Table 2.1: sin deviations of FFOV and Map angles (absolute value of "sin-sin")

2) Complexity (three levels)-Scenes were categorized by number of features available for comparison. Scenes that were considered the lowest level of complexity had relatively few features for comparison. For instance, the scene may have just had one road with a bend in it, or a terrain feature with a single peak. A scene defined by the third level of complexity might have numerous roads with bends in them, several peaks with rivers that bent around them, or an industrial complex with several road and waterways surrounding it. Scenes depicting the second level of complexity would be somewhere in between. Categorization of complexity level was at the judgment of the experimenter.

3) Feature type (two levels)- Scenes were further divided into two levels of feature type. Scenes were categorized as depicting primarily natural features, or primarily cultural or man-made features.

Four sequences were generated with 96 "same" (16 x 3 x 2) and 48 "different" trials. The order of the 144 trials in each of the four different sequences was randomized. An approximately equal number of subjects (6 or 7) was assigned to each sequence. The 2:1 ratio of "sames" to "differents" is consistent with previous navigational checking studies and was chosen for several reasons. First, it is assumed that in normal navigational scenarios, the two views will "match" more frequently than they will "mismatch". Secondly, the nature of scene alterations to create

"different" trials are varied, and hence the source of latency on these was also variable and not well controlled. Therefore, the contribution to performance on these trials is harder to interpret. Finally, because "same" trials were potentially more interesting and yielded more useful information, having more "sames" produced more data and hence increased power to examine the experimental hypothesis. To avoid a speed accuracy tradeoff and to avoid a bias for subjects to respond one way or the other, they were not informed of this ratio and were offered an incentive for high accuracy. In addition, subjects were verbally instructed to avoid a speed accuracy tradeoff and were forced to make a decision within twenty seconds, otherwise the trial was counted as incorrect.

Procedure

Each subject participated in one session lasting approximately one hour. After reading the instructions, subjects were situated in the chair and verbally briefed salient highlights of the instructions by the experimenter. Specifically, subjects were instructed to avoid making rapid guesses. After this instruction period, subjects were presented with 8 practice trials to familiarize them with the task. The practice trials were then followed by 144 experimental trials. A short break was offered at the middle of the experimental trials; however, only one subject took the break while all others worked through without taking a break.

At the start of each trial, a small "X" appeared in the center of the IRIS display and subjects were instructed to fixate on it. After three seconds, both the IRIS display (map), and the screen projection of the Evans & Sutherland computer (FFOV) would appear. Subjects then responded either "same" or "different" via the joystick as soon as they had made their decision. Subsequently, both screens went blank for two seconds, and a new trial was initiated with the appearance of the "X". Following completion of the experimental trials, subjects were given a post-experiment questionnaire (appendix B).

Results

All statistical analyses were performed using SYSTAT version 5 for Windows™ and version 6 for DOS™. The twenty-six subjects provided a total of 3744 experimental trials. Because of computer anomalies, four trials were removed. Of the remaining 3740 trials, 2495 were "sames" and 1245 were "differents." All error bars depicted on the figures represent a 90% confidence interval. An initial analysis of variance on individual differences in subject speed and accuracy revealed overall significant subject effects on both dependent measures [($F(25,3714)=3.225$, $p<0.001$] with accuracy, and [$F(25,3714)=71.759$, $p<0.001$] for response time). However, there were no subjects that had overall means exceeding two standard deviations from the combined means, therefore all remaining data was used for the subsequent analysis. There was also an apparent small learning effect for response time but not for accuracy. As can be seen in figure 3.1, response times generally decreased while accuracy remained constant throughout the experimental trials. This trend was generally consistent with all subjects individual response times and accuracy; therefore, they were not considered to significantly affect other analyses. This finding is also not surprising as the post experiment questionnaire revealed 38% of subjects (n=10) felt that they became familiar with the "world" after only 1/4 of the trials and 46% (n=12) after only 1/2 of the trials (limited selection of viewing area). All but one (n=25) felt that this familiarity was helpful in the task and reduced response times.

Response Type

A test was performed on trial type (same vs. different) using accuracy as the dependent measure. Results indicated that accuracy on different trials was 5.3 % lower ($t_{3738}= 4.83$, $p<0.001$) than same trials (see figure 3.2). Given the dichotomous nature of the response class, this suggests the presence of a "response bias" effect; whereby, when in doubt about the nature of the match, subjects will guess the more frequent stimulus ("same"), and hence, lower their accuracy on same trials. That is, subjects were more apt to say "same" disproportionately more often then "different" when in fact it was a "different" trial, compared to subjects responding "different" when it was a same trial. Additionally, a 2x2 ANOVA was also performed on the response time data using trial type (same or different) and response accuracy (correct vs. error) as factors (figure 3.3). Results revealed that correct responses were significantly faster than incorrect responses [$F(1,3736)=196.217$, $p<0.001$], and "different" trials were significantly faster than "same" trials [$F(1,3736)=61.097$, $p<0.001$]. A significant interaction [$F(1,3736)$, $p=0.002$]

between the two variables indicates that there was greater delay on "same" trials for incorrect responses than for correct responses. The greater RT for "same" responses than for "different" responses suggests that subjects engaged in a self-terminating search strategy (Wickens, 1992; Cooper, 1980), truncating their search when a mismatching feature was found.

Further analysis of the differences between "same" and "different" trials suggests that search strategy might be modulated by complexity. This is revealed by significant interactions between trial type and complexity level in both speed [$F(2,3734)=18.841$, $p<0.001$]and accuracy [$F(2,3734)=33.452$, $p<0.001$] as seen in tables 3.1 and 3.2 (below) and figure 3.4. The results indicate that with low complexity, an exhaustive search for features may occur, and when there is uncertainty about the existence of a mismatching feature, subjects will guess "same". However, at higher complexity levels, there is a greater tendency to engage in a self-terminating search strategy, again truncating the search as soon as a "different" feature is found, but continuing search (and thereby prolonging response time) if one is not found.

Source	SS	DF	MS	F	P
Complexity	175.812	2	87.906	7.349	**0.001**
Trial type	605.626	1	605.626	50.632	**<0.001**
Complexity X trial type	450.757	2	225.379	18.841	**<0.001**
Error	44665.679	3734	11.962		

Table 3.1: Analysis of Variance (Complexity X Trial type, **response times**)

Source	SS	DF	MS	F	P
Complexity	3.732	2	1.866	19.296	**<0.001**
Trial type	2.306	1	2.306	23.845	**<0.001**
Complexity X trial type	6.470	2	3.235	33.452	**<0.001**
Error	361.114	3734	.097		

Table 3.2: Analysis of Variance (Complexity X Trial type, **accuracy**)

Collectively, these results enable the following interpretations: 1) The fact that "sames" take longer than "differents" indicates a serial self-terminating search for sameness is often performed. 2) There is variance between trials in the ease of detecting these differences. When "same" detection is difficult, it is both time consuming and more likely to be error prone. 3) On some small percentage of these difficult trials, subjects will abandon the search prematurely and guess "same" leading to a greater number of "fast errors" on the "different" than the "same" trials, and thus inflating the overall error rate for "differents" (figure 3.2), and increasing the latency

advantage of "different" trials for incorrect responses. These interpretations also suggest that "different" trials do not predict performance in the same manner as "same" trials. Spurious predictions at best can be made with "different" trials (see figure 3.5), hence further analysis will be focused using only the "same" trials (which as we noted, constitute the majority of the data, and the more typical confirmation behaviors in navigational checking).

A 16x3x2 (sin-sin deviation x complexity x feature type) analysis of variance was performed using response times and accuracy as separate dependent measures. Response time results indicated significant differences due to sin-sin deviation, complexity, and feature type. Additionally there were significant interactions between sin-sin deviation and feature type, and complexity and feature type. See ANOVA table 3.3 below.

Source	SS	DF	MS	F	P
Sin-Sin Deviation	961.725	15	64.115	5.395	**<0.001**
Complexity	776.236	2	388.118	32.658	**<0.001**
Feature type	301.383	1	301.383	25.36	**<0.001**
Sin-Sin x Complexity	409.400	30	13.647	1.148	0.265
Sin-Sin x Feature type	296.995	15	19.8	1.666	**0.051**
Complexity x Feature type	274.526	2	137.263	11.55	**<0.001**
Sin-Sin x Complexity x Feature type	395.82	30	13.194	1.110	0.311
Error	28510.619	2399	11.884		

Table 3.3: Analysis of Variance (response times)

Analysis of variance on accuracy revealed significant main effects with all variables and significant interactions with everything but sin-sin x complexity. The summary table is listed below (Table 3.4).

Source	SS	DF	MS	F	P
Sin-Sin Deviation	3.143	15	.210	2.571	**0.072**
Complexity	0.429	2	.214	2.631	**0.001**
Feature type	1.486	1	1.486	18.239	**<0.001**
Sin-Sin x Complexity	3.087	30	.103	1.263	0.155
Sin-Sin x Feature type	2.457	15	.164	2.010	**0.012**
Complexity x Feature type	1.161	2	.580	7.123	**0.001**
Sin-Sin x Complexity x Feature type	5.602	30	.187	2.291	**<0.001**
Error	195.494	2399	.081		

Table 3.4: Analysis of Variance (accuracy)

Elevation angle deviation effects

Figure 3.6 depicts response time and accuracy as a function of the signed angular disparity between the map and the FFOV. Figure 3.6a, which presents response time as a function of the signed angular deviation between map and FFOV, presents a pattern of results which resemble the findings by previous researchers as response time tended to be lowest around 0° angular deviation and increases non-linearly as the deviation increased (Goldberg et al. 1992, Schreiber et al. 1995). The figure also suggests that negative deviations (map angle is greater than FFOV angle) produced worse performance then positive deviations; replicating findings observed by Schreiber et al.

Because of the number of levels of this variable, regression analysis on response time and accuracy yields more useful information than a simple ANOVA. This analysis uses as its independent variable the absolute value of the difference between the map and FFOV elevation angles, collapsing over positive and negative deviations. Figures 3.7 and 3.8 illustrate the graphical results of this analysis with corresponding regression lines and explained variance (R^2). Figures 3.7a (RT) and 3.7b (accuracy) are plotted using angular deviations as the abscissa whereas figures 3.8a (RT) and 3.8b (accuracy) uses sin-sin deviations. In figure 3.7, angular disparity accounts for 38.27% of the variance on response time and 20.75% of the variance on accuracy. However, a similar regression onto the sin-sin deviations (again in terms of absolute value) shown in figure 3.8a, yields a much greater amount of variance accounted for, 75.57%. Similarly, accuracy is reduced as the difference between the sin values increases with 52.33% of the variance accounted for (figure 3.8b). Comparing figure 3.7 with 3.8 indicates the greater strength of the linear fit using sin deviations. The regression lines reveal that differences between 0 and large disparity costs approximately 1.5 seconds in response time, and an 8% loss in accuracy.

Figure 3.9 presents the response time and accuracy data as joint functions of FFOV angle (the abscissa) and map angle (the parameter). Although the experimental design did not allow a statistical examination of map angle, unconfounded by disparity, visual examination of the data fails to reveal any apparent monotonic trend of performance across map angle (levels on the abscissa), for response time; however, there does appear to be a general downward trend in accuracy as map elevation angle increases. The data also suggests a trend for performance to be

poorest at low FFOV angles, although this trend is contraindicated by the data for the lowest map angle (15°). Additionally, the data indicates that the least amount of variance in response times across all FFOV angles occurs with a 45° map angle while variance in accuracy remains fairly constant for all map angles except for 60°.

Complexity

The effect of complexity is shown in figure 3.10. The analyses of variance summarized in tables 3.3 and 3.4 reveal a significant effect on response time [$F(2,2399)=388.118$, $p<.001$] and accuracy [$F(2,2399)=2.631$, $p=.001$] suggesting there were differences in performance affected by complexity level. Both the analyses and figures reveal the loss of performance as image complexity increases. For accuracy, this effect is monotonic across the 3 complexity levels. However, for response time, it does not distinguish between the highest two levels. Indeed, this may represent a slight speed accuracy tradeoff: at high complexity levels, there may be a tendency on some trials to make a "fast guess." As we see below, this guessing strategy may be reflected only with the most difficult natural features.

Feature type

ANOVA tables 3.3 and 3.4 also reveal significant differences on both response time [$F(1,2399)=25.36$, $p<.001$] and accuracy [$(1,2399)=18.239$, $p<.001$] between natural and man-made features. As figure 3.11 indicates, scenes that depicted primarily man-made features were responded to approximately 0.7 seconds faster than scenes depicting primarily natural features and were also 4.9% more accurate. In the post-experiment questionnaire, subjects were asked "What features were most helpful when making judgments? In other words, what features helped you compare the two views faster?" On average, man-made features were listed 37% more frequently than natural features (48/35).

Interactions

The ANOVA tables reveal no significant interaction between sin deviations and stimulus complexity for response time [$F(30,2399)=1.148$, $p=0.265$] and accuracy [$F(30,2399)=1.263$, $p=0.155$]. However, figure 3.12 depicts the significant interactions between the sin deviations and feature type (response time [$F(15,2399)=1.666$, $p=.051$] and accuracy [$F(15,2399)=2.010$, $p=.012$].) As the deviation increased it appears that scenes depicting primarily natural features were more negatively affected than scenes depicting cultural or man-made features.

Figure 3.13 depicts the significant interaction between complexity level and feature type. The ANOVA tables reveal significance for response time [$F(2,2399)=11.55$, $p<.001$] and accuracy [$F(2,2399)=7.123$, $p=.001$]. The data suggest that with simpler scenes, natural features suffered a cost in both speed and accuracy. However, at the most complex (and therefore difficult) level, maps with the most difficult natural features suffered in accuracy, possibly from a "fast guess" strategy, yielding faster response times, but considerably reduced accuracy.

Figure 3.1a. **Response time as a function of trial number**

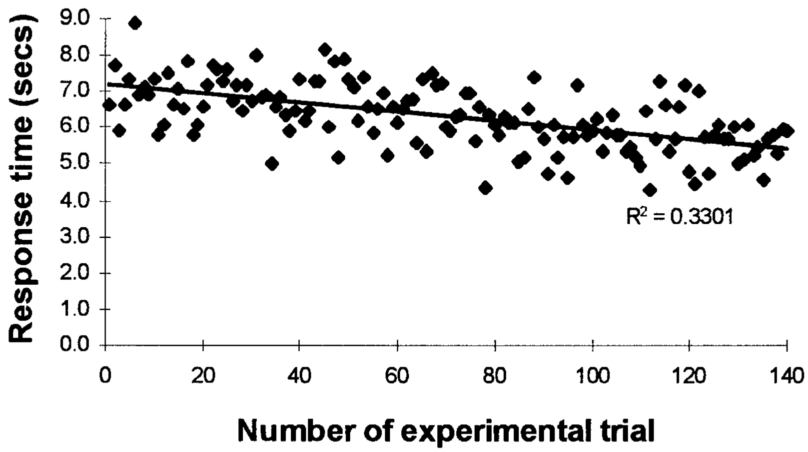


Figure 3.1b: **Accuracy as a function of trial number**

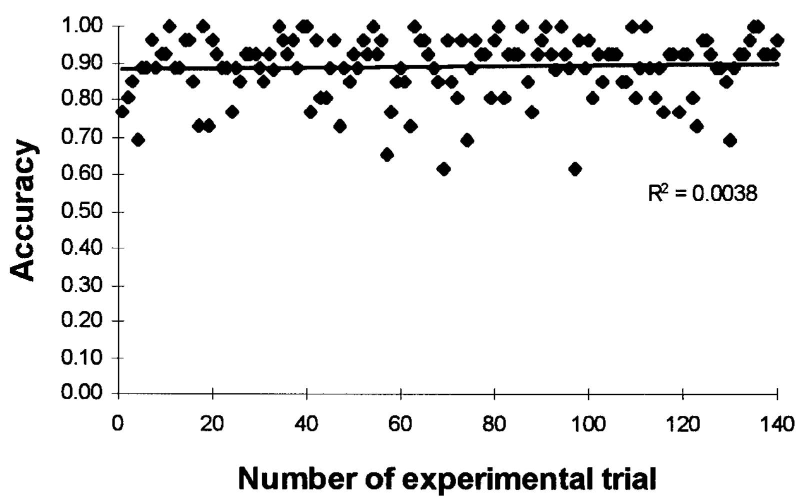


Figure 3.2: **Accuracy as a function of type of trial**

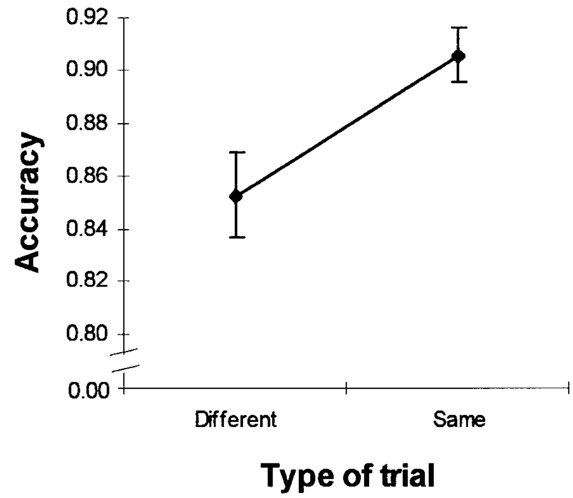


Figure 3.3: **Response time as a function of accuracy by trial type**

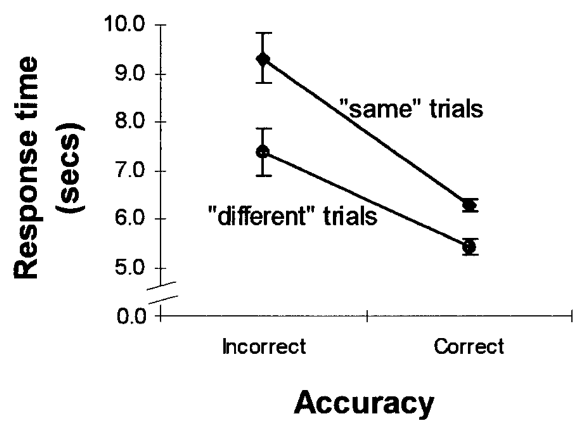


Figure 3.4a: **Response time as a function of the interaction of trial type and complexity**

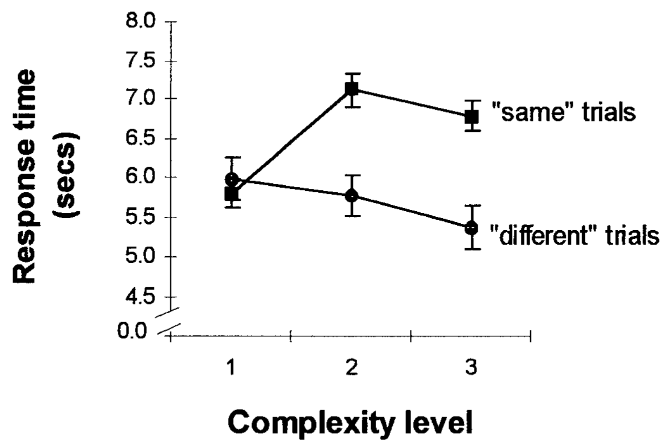


Figure 3.4b: **Accuracy as a function of the interaction of trial type and complexity**

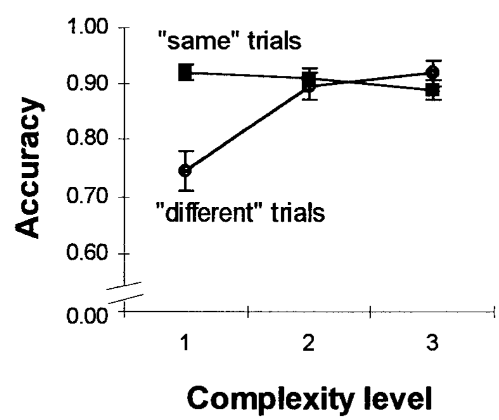


Figure 3.5a: **Response Time as a function of the absolute value of the SIN difference between FFOV and Map elevation angles [abs(sin(map)-sin(ffov))] (w/regression and R^2) "different" trials**

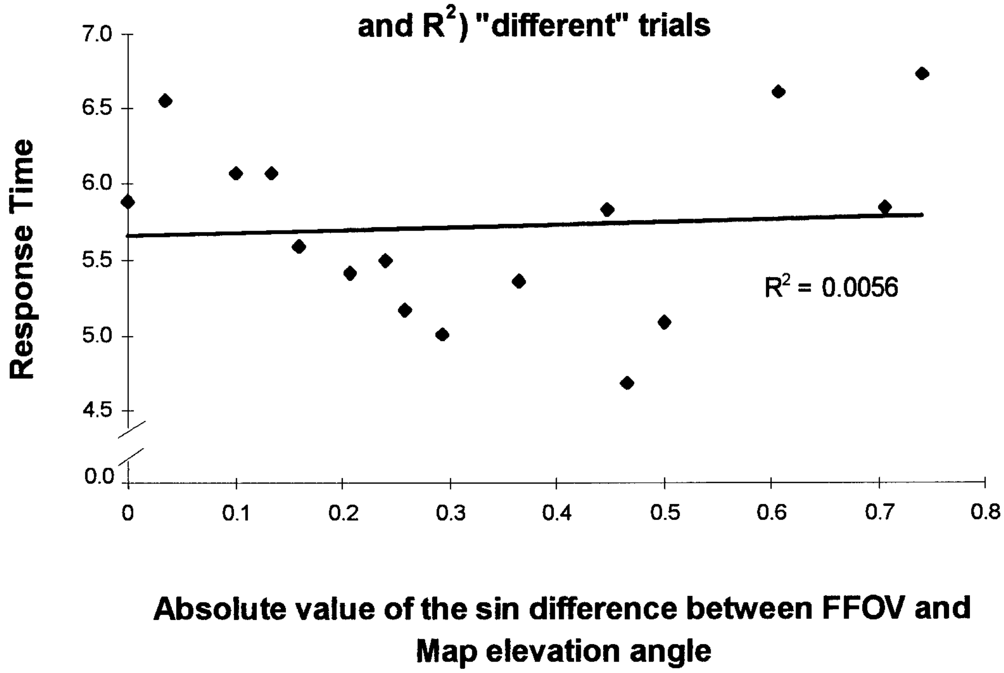


Figure 3.5b: **Accuracy as a function of the absolute value of the SIN difference between FFOV and Map elevation angles [abs(sin(map)-sin(ffov))] (w/regression and R^2) "different" trials**

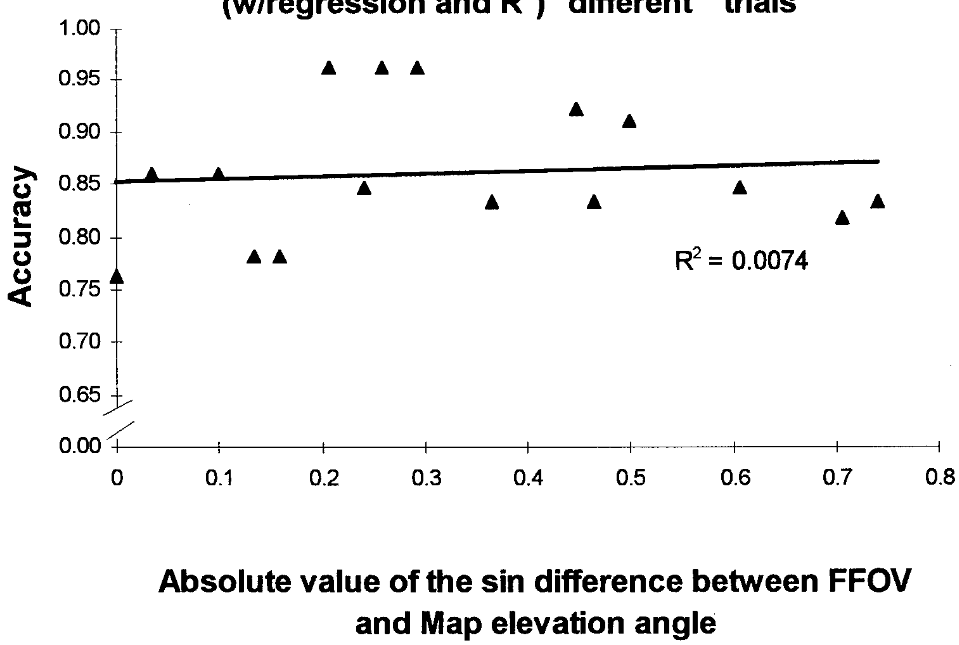


Figure 3.6a: **Response time as a function of map elevation angle and elevation angle disparity from FFOV**

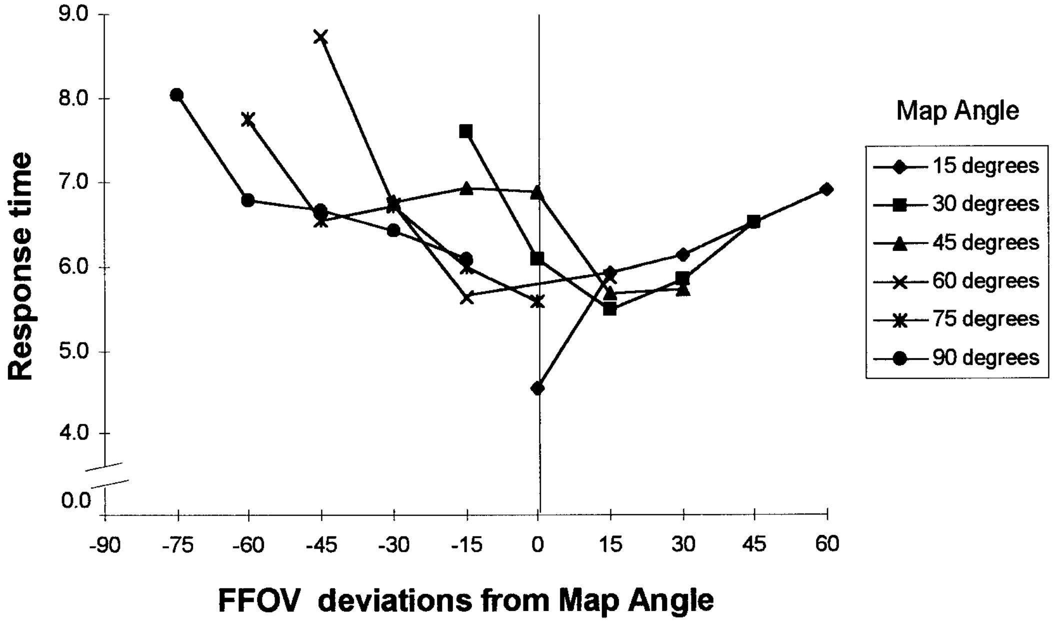


Figure 3.6b: **Accuracy as a function of elevation angle and elevation angle disparity from FFOV**

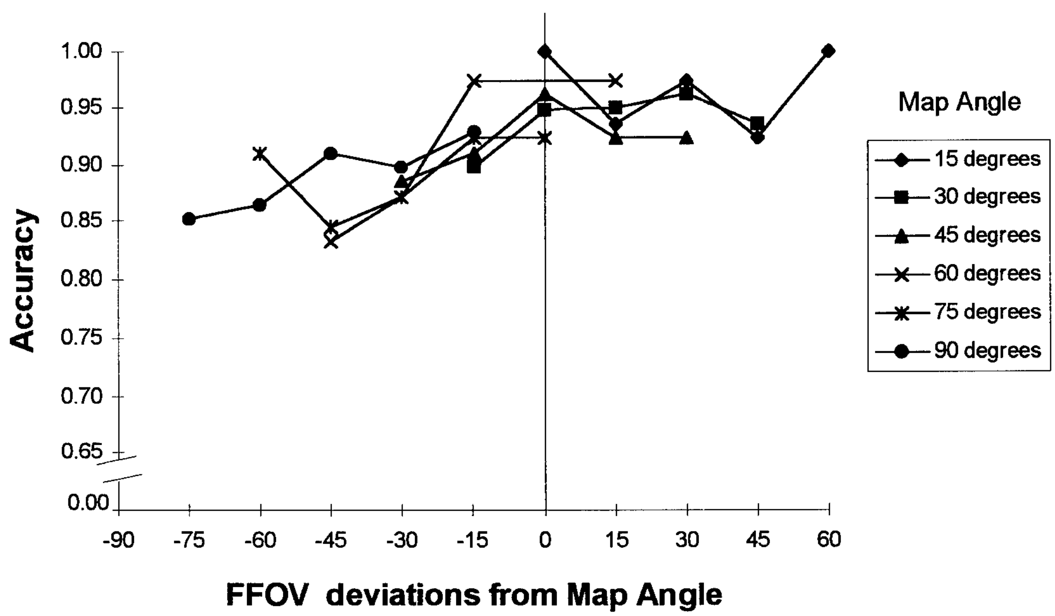


Figure 3.7a: **Response Time as a function of Angular Disparity**

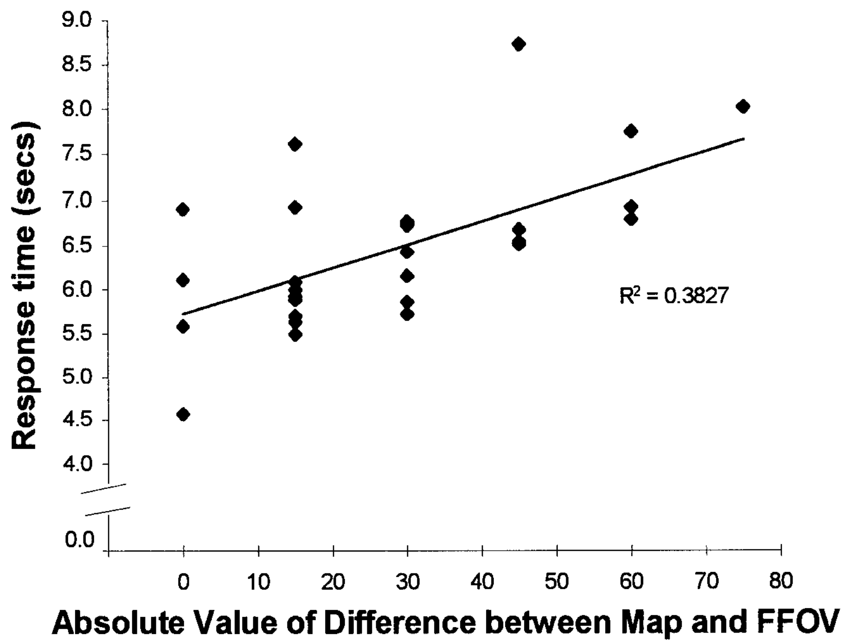


Figure 3.7b **Accuracy as a function of Angular Disparity**

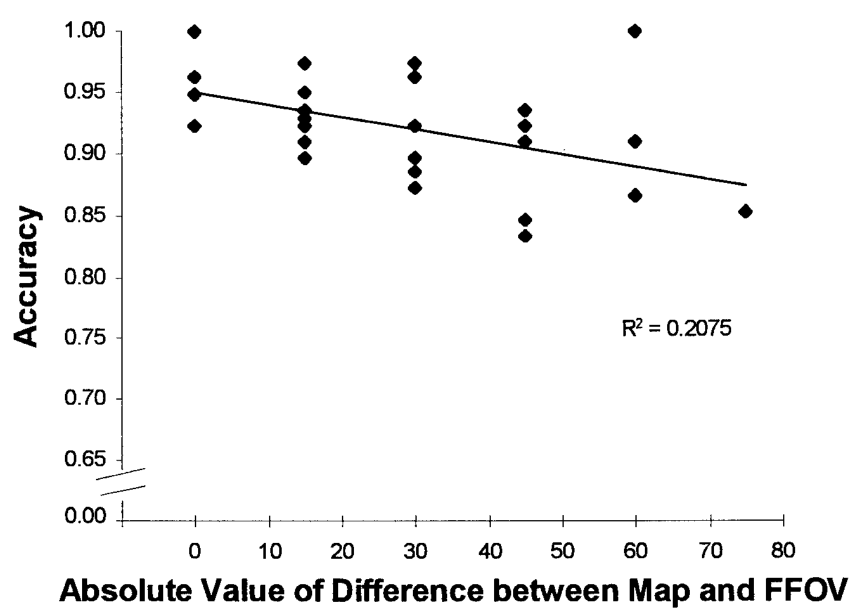


Figure 3.8a: **Response time as a function of the absolute value of the SIN difference between FFOV and Map elevation angles [abs(sin(map)-sin(ffov))] (w/regression and R^2)**

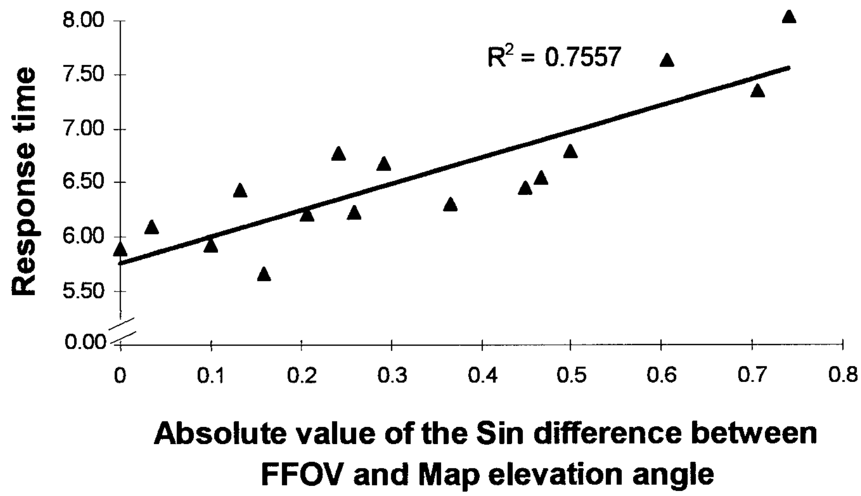


Figure 3.8b: **Accuracy as a function of the absolute value of the SIN difference between FFOV and Map elevation angles [abs(sin(map)-sin(ffov))] (w/regression and R^2)**

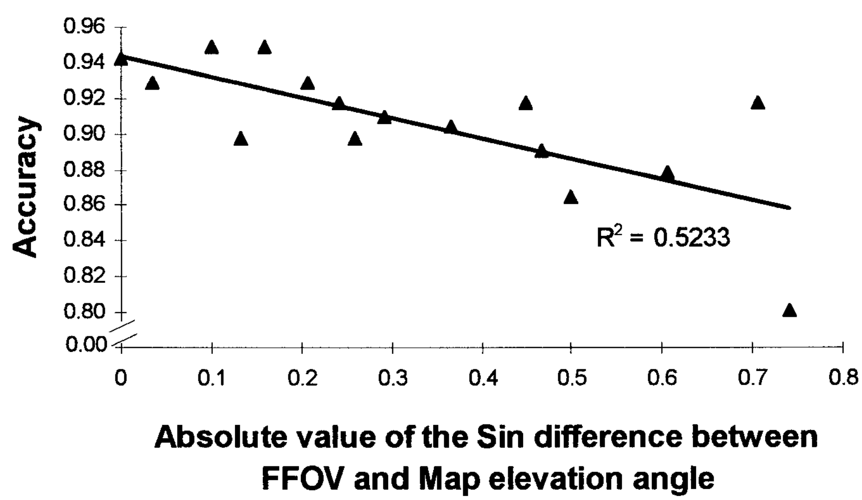


Figure 3.9a: **Response time as a function of the interaction of map and FFOV angle**

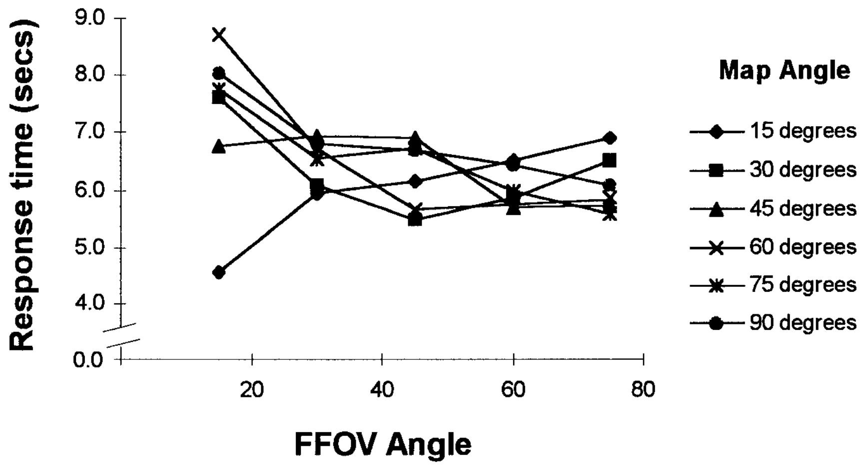


Figure 3.9b: **Accuracy as a function of the interaction of map and FFOV angle**

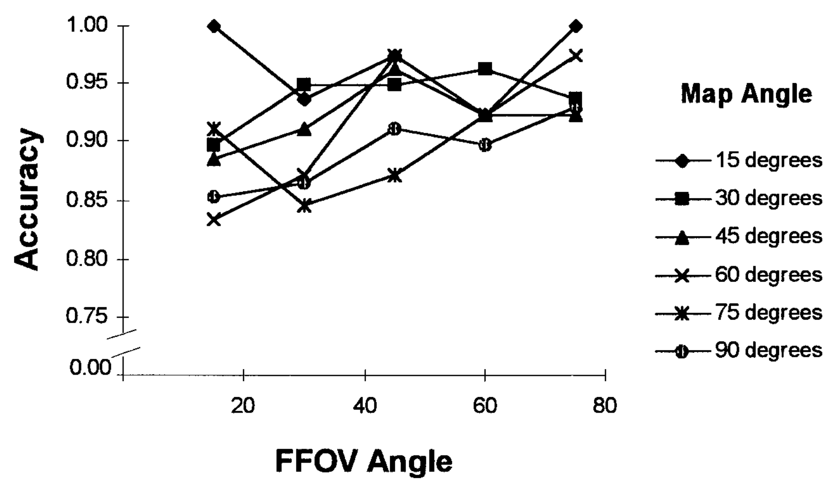


Figure 3.10a: **Response Time as a function of Complexity Level**

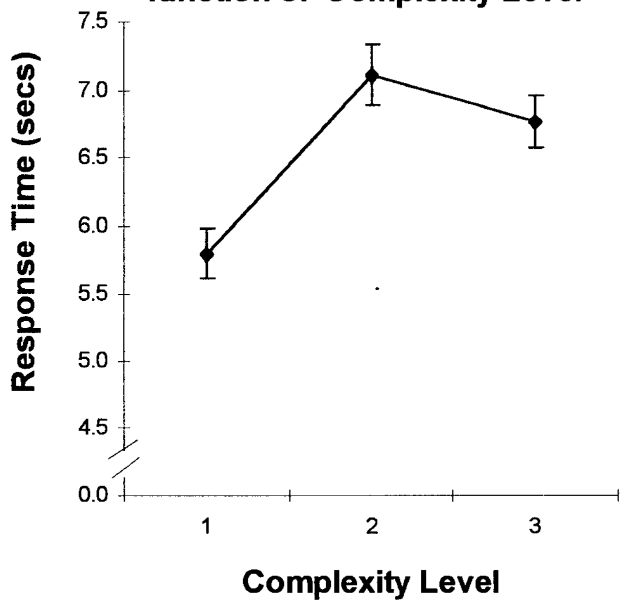


Figure 3.10b: **Accuracy as a function of Complexity Level**

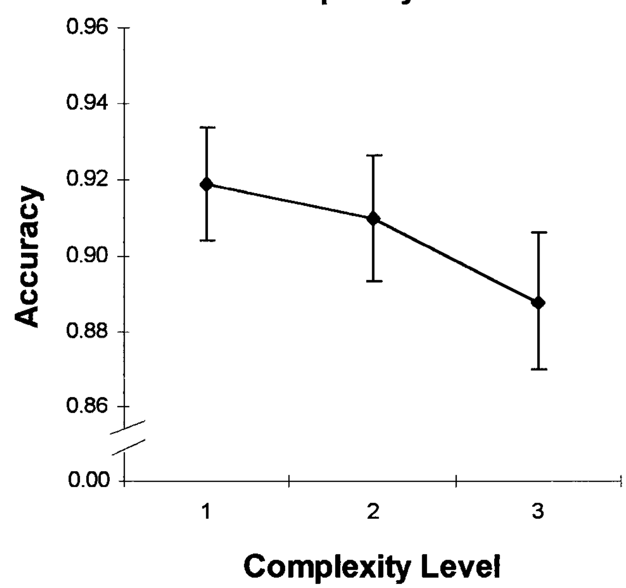


Figure 3.11a: **Response times as a function of feature type**

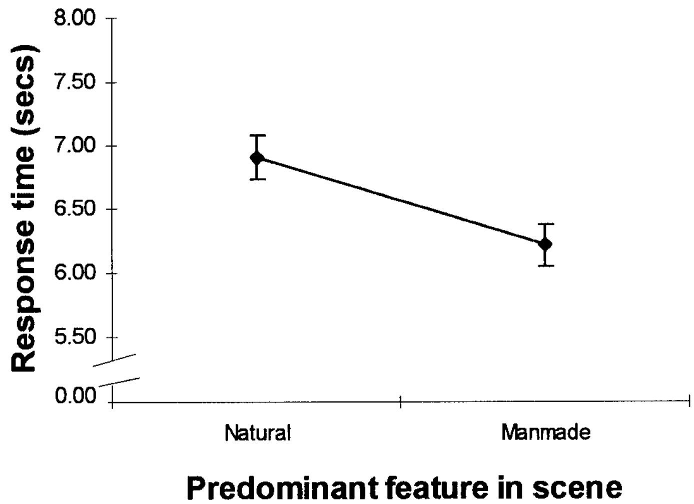


Figure 3.11b: **Accuracy as a function of feature type**

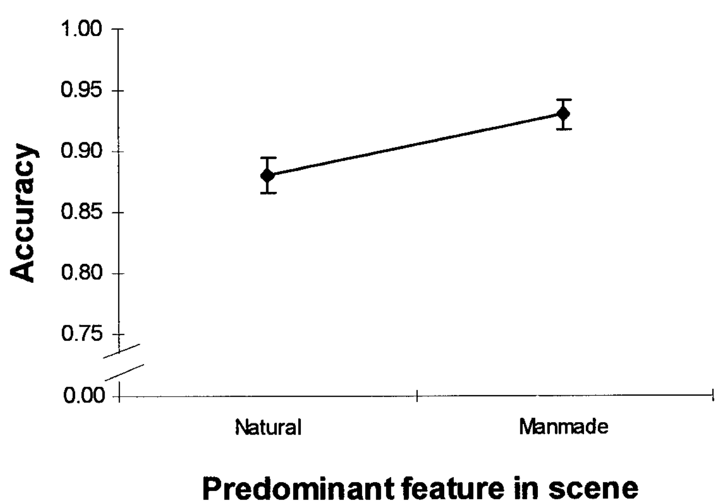


Figure 3.12a: **Interaction of sin deviations with feature type (response time)**

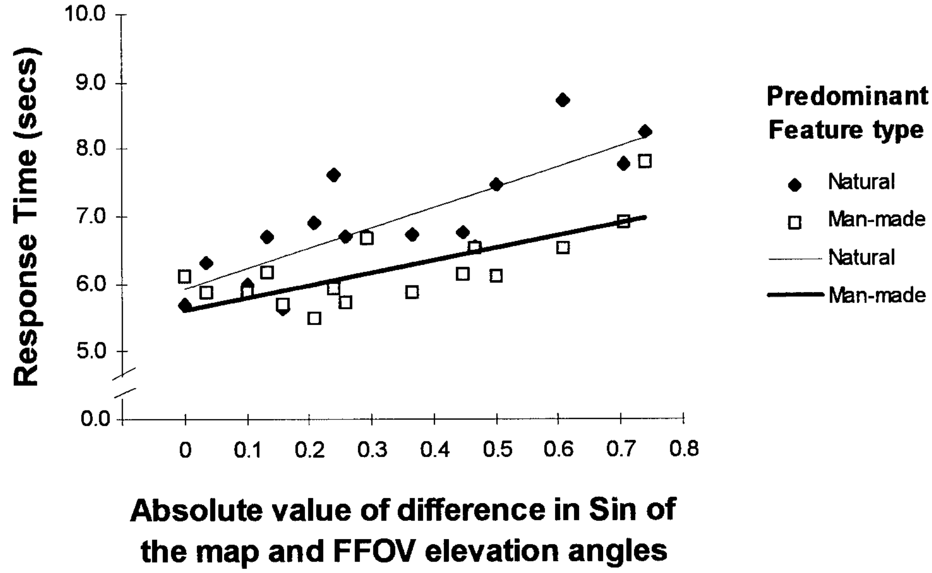


Figure 3.12b: **Interaction of sin deviations with feature type (accuracy)**

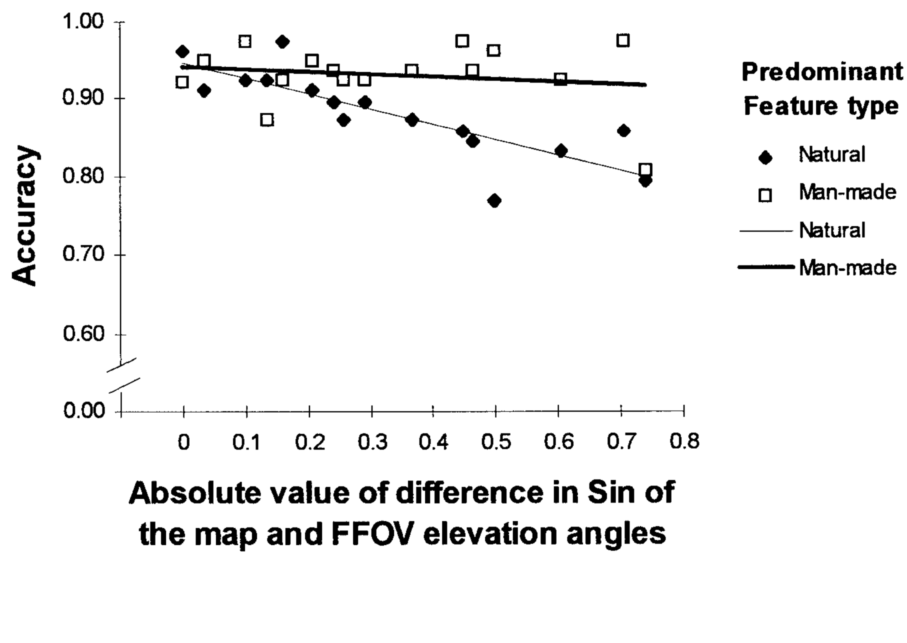


Figure 3.13a: **Interaction of complexity level with feature type (response time)**

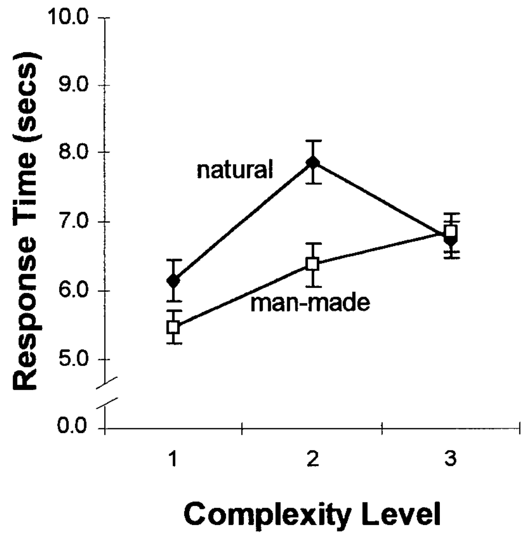
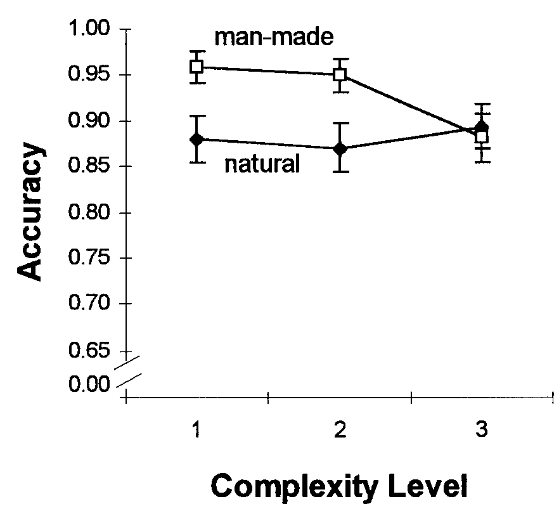


Figure 3.13b: **Interaction of complexity level with feature type (accuracy)**



Discussion

This study sought to examine the effects of different manipulations of map displays on the navigational checking task. The primary variable of interest was the amount of difference between the sin of the elevation angles of the map and the sin of the FFOV and its effect on response time and accuracy. Additionally, the effects of complexity and feature type (defined by man-made vs. natural) were investigated. In the following discussion, we explore the effects of the experimental manipulations on response time and accuracy, in conjunction with an examination of the search strategies involved in the task, and finally relate this to the practical applications in the design of electronic maps.

Sin-sin transformation

In previous mental rotation studies of objects, researchers found that in general, latencies were linearly related to the amount of angular disparity. Cooper & Shephard(1973) and Cooper & Podgorny (1976) found this using 2-dimensional objects, and Metzlar & Shephard(1974), Shephard & Metzlar(1971) and Steiger and Yuille (1983) found this using 3-dimensional objects. In studies that involved the rotation of 3-dimensional scenes or viewpoints, this relationship was not quite as definitive. Using topographic representations, Goldberg et al. (1992) found that response times were linearly related to azimuth angle disparities. However, in other studies that examined the same effect, Aretz (1991), Aretz and Wickens (1992), and Schreiber et al. (1996) noted a monotonic, non-linear relationship between response time and azimuth disparity. Although he attributed the linear effect of response time costs in object rotation studies to mental rotation, Wickens (1996) ascribed an alternative underlying mechanism, called "symbolic transformation" or reversal mapping, as an explanation to the non-linearity of response time costs in azimuth disparity with scene or viewpoint comparisons. He suggested that the costs are distinctly non-linear, smaller when rotations are less than 90° and larger when they are greater than 90°, at which time mappings must be reversed.

In a similar manner, latencies produced by elevation angle disparities in viewpoint and scene comparisons are not consistent with a strict mental rotation model as the relationship between the two is clearly non-linear. Eley (1988) and Aretz and Wickens (1992) substantiated this assertion by finding that the relationship between response time and angular disparity followed a non-linear function. Aretz and Wickens stopped short of calling it mental rotation, preferring to refer to it as "envisioning." Schreiber et al. (1995) found similar data patterns, and

referred to the phenomenon as a "special instance of elevation angle mental rotation", while Goldberg et al. (1992) concluded that the strategy of comparing the images may not even involve a transformation about an axis (as with mental rotation). They further suggested that the transformation strategy possibly involved a combination of mental rotation with "cue-dependence", based on encoding features that were equally recognizable at all orientations, then using these feature to make same/different judgments.

The current study replicates the findings of a cost to elevation angle disparity found by Schreiber et al. (1995) and Goldberg et al. (1992), but the careful design here allowed for a better examination of the nature of this cost. We have found that the effects of elevation angle rotation are modeled better as a function of the difference in the sin of the two angles than by simply using the difference in the angles. This study used this transformation process as a primary manipulation and has given more solid evidence for this phenomenon than that revealed by the post hoc analysis of the Schreiber et el. and Goldberg, et al. data. The nature of this transformation is summarized below.

An examination of the objects in figure 1.4 (page 18) graphically illustrates how objects depicted in a scene are affected by changes in the viewed elevation angles. At the highest elevation angle (-90°), the amount of horizontal information (resolution) of the map compared to the FFOV is at its greatest level (map 1). With a decrease in map elevation angle, the shape, orientation, and perceived relative position of objects becomes closer to those of the FFOV (map 2). At a map elevation angle of 30° (map 3), one would expect no cost no elevation angle transformation costs as the map angle equals that of the FFOV. Finally, at 0° (map 4), there is no horizontal information indicated at all, therby inducing additional costs not only in the transformation of the angular disparity, but also in the pilots interpolation of the relative position and even existence of some objects (road not in view). As indicated by this figure and in figure 1.5 (page 18), the amount of horizontal resolution in the viewed image follows a sin function. In the case of air navigation. horizontal information is more relevant to the task at hand (Wickens, 1994) so the sin function is more appropriate to describe the amount of change in the relevant features of the images. This suggests that small angular disparities at low altitudes (low angle FFOV coupled with a low angle map) have a more dramatic effect on response time, than an equal angular disparity at higher altitudes (high FFOV with a high map angle). In fact, data from the present research confirm this. We successfully model the angular disparity costs as a linear

function of the sin disparity, accounting for over 75% of the variance in response time and over 53% of the variance in accuracy.

Search strategy

The fact that complexity did not interact with elevation angle disparity (see ANOVA tables 3.3 and 3.4) suggests that the locus of the complexity effect was on search, rather than image transformation. Had complexity influenced the image transformation, then we would anticipate the more complex stimuli would produce a greater effect of disparity. Such was not observed. Although search strategy was not of primary interest during this study, by examining the effects of the nature of the choice (same/different) and complexity, we find interesting patterns in the data which would suggest a particular search strategy. The model of navigational checking (figure 1.3, page 7) indicates that the comparison process between map and FFOV is in fact a serial task; however, indications of the type a search within successive viewings of the each respective view are not represented. Figures 3.2 and 3.3 illustrate the comparison of "same" and "different" reaction times and show that "different" judgments were significantly faster than "same" judgments, suggesting that a serial self-terminating search strategy was used. On "different" trials, subjects terminated the process as soon as a difference was found and did not have to continue the search. On "same" trials, we assume that they continue their search for a longer time. The current data (see figure 3.4, page 42) suggest that this self-terminating search strategy is only engaged with more complex images. It may be that the comparison with simpler images is made using a more exhaustive search strategy for both "sames" and "differents." As a parallel alternative, it could be that an "holistic" strategy is used. As a third possibility, the search strategy may be serial and self-terminating, but the cost for "same" which normally emerges in search tasks, might be offset by the overall benefit for a "same" response in same/different judgment tasks, which is observed by investigators using non-search paradigms, (Kreuger, 1978; Proctor, 1981; Ratcliff, 1981).

There are two findings that are interesting with respect to feature type: 1) navigational checking is more efficient when scenes involve primarily man-made features (figure 3.8) and 2) The effect of angular disparity exacerbate the difference in performance caused by feature type (figure 3.9). Both of these phenomena are discussed below.

Finding 1 above confirms the assertion of Whitaker & Cuqlock-Knopp (1995) that there are useful visual cues not found in naturalistic environments that are available in man-made

settings which are helpful in the determination of position and orientation while map reading. These features include, straight lines and right angles. In the present research, it appears that the man-made features were more easily and readily encoded; therefore the iterations between the map and FFOV containing man-made features (figure 1.3, page 7), were considerably fewer than with scenes involving exclusively natural features. Finding 2 above is a confirmation of what Biederman (1995) and Wiebe and Converse (1996) found when distinguishing between viewpoint invariant and viewpoint dependent features. According to their distinction, recognition and classification, viewpoint invariant features, which are more likely to be cultural or man-made features, is relatively independent of how the scene is viewed. Thus, bridges, factories, and airfields (features used in the present study) look like bridges, factories, and airfields from most elevation angles, and no mental transformation is necessary to determine what they are. Viewpoint dependent (i.e. natural) features such as mountains or lakes, will vary in their perceptual shape as a function of viewpoint, and therefore may require more transformation to be categorized.

It is clear from the work of others coupled with the data from the present research, a combination of cognitive mental transformations are interacting in the navigational checking task. While the sin transformation of elevation angle disparity alone accounts for much of the variance, additional sources of variance arise from the processing of viewpoint invariant and viewpoint dependent features. Because it is does not appear to interact with angular disparity, the effect of complexity seems to be mediated by the type of search strategy involved. Assuming that the major transformations affecting this process are the combination of the sin transformation and the processing of viewpoint invariant and viewpoint dependent features, we refer to this phenomena as "trigonometric cue envisioning".

We use the term "trigonometric" because the cognitive process involves the use of trigonometric multiplicatives of the map and FFOV angles. The amount of horizontal and vertical resolution in the viewed image follows the sin and cosine function respectively. For a pilot engaged in the navigational checking task, one would expect that processing of a scene which is dominated by viewpoint dependent features would follow the sin trigonometric function fairly closely, but the costs of the cognitive transformations required would certainly be mediated with the addition of viewpoint invariant features (cues). It is for this reason that we include the term

"cue envisioning", for with the addition of viewpoint invariant features, the costs of the trigonometric transformation processing of viewpoint dependent features would be ameliorated.

Although elevation angle disparity was the primary variable of interest in the present study, a similar model that addresses the non-linearity of latency involved with azimuth angle disparities may be appropriate as well. The shape and relative positioning of objects in a scene also change as a trigonometric function as the scene is rotated about the lateral axis.

Map design

Ultimately, the effects of these variables should be of significant interest to the designers of electronic maps. The general assumption of this paper is that including all possible features on a map may not be cost effective and possibly may not be necessary. The question remains as to which features need to remain in order to maintain efficient navigational checking. The independent variables are discussed in terms of their relevance to map design.

1) Sin-Sin disparity. The practical significance of modeling the elevation angle disparity in terms of the difference in the sin values has important applications for the speed of dynamic updating of maps. Consistent with the findings and recommendations of Schreiber et al., if small disparities do not matter (e.g. higher FFOV's coupled with higher map angles) then dynamic updating does not need to be so fast (to keep up with minor deviations.) Instead, discrete changes in map angle should be presented more frequently, only when the image differences are fairly large and therefore when disparity matters. At FFOV elevation angles of 45° or greater, the efficiency of navigational checking is nominally affected by changes in the elevation angle of the map (figure 3.9, page 47). However, it does appear that higher map angles (75°,90°) do not promote the efficiency that mid-range map angles (30°-60°) afford. What is definitive in this study is that 90° maps are not the most effective, and it appears that 45° maps offer the least variance in efficiency across all FFOV angles. This finding is consistent with the work of Yeh and Silverstein (1992), who examined an altitude/depth judgment task, and Ellis and Kim (1985) who had subjects perform a tracking task.

It is conceivable that most low-level navigational checking would occur at FFOV angles less 45°. For example, the pilot of a combat aircraft at an altitude of 500 ft, traveling at 500 knots, will be looking ahead of the aircraft at least 5 miles, producing an FFOV elevation angle of less than 1°. A pilot would have to be looking less 200 yards in front of the aircraft in order to have a 45° FFOV, a distance which is highly improbable given the speed and nature of most

combat missions. An examination of the regression lines in figure 3.8 (page 46) indicates the loss in efficiency as elevation angle disparity increases. The figure reveals an 8% loss in accuracy for large disparities (e.g., a 90° map with a low angle FFOV) and although the 1.5 second increase in response times for large disparities may seem negligible, for a combat aircraft flying at 500 knots, this latency translates into almost 1/4 mile distance traveled, a nontrivial span. A similar scenario can be envisioned for general aviation pilots, however, the range of FFOV angles would be much greater. Most general aviation cross-country or navigation occurs between the altitudes of 1000 to 5000 feet. Even at 5000 feet a 45° FFOV would center a pilots attention only 1 mile ahead of the aircraft, a distance traveled in 30 seconds or less. Given the nature of navigation and the range of FFOV angles typically employed, we would recommend that for higher altitude navigation (above 5000 ft) static maps at 45° elevation angle could be utilized and efficient navigational checking maintained. Below 5000 ft, a breakdown in efficiency could be expected to occur with static maps, therefore dynamically updated maps that match the momentary slant angle of the pilot looking out of the aircraft (FFOV) would be recommended.

2) Complexity. Recommendations for map design with respect to complexity would be indeterminate. The general finding of this study is that increasing complexity did reduce performance, but the nature of the experimental design prohibits the determination of whether it was map or FFOV complexity that mattered the most. Complexity does effect navigational checking, yet how does one design for it? How does one manipulate the complexity of a map to improve efficiency? A variable of interest that was not manipulated in this study is map simplification. It is possible to remove features of a map and still maintain efficient checking, but the question remains as to which features of a map to remove. Given that the data suggests that judgments of orientation and position using man-made or cultural features are (a) made faster, and (b) more viewpoint invariant, we would recommend highlighting those features to make them more salient and not consider removing them in any map simplification. Given the overall effect of complexity on the navigational checking process, designers should be cognizant that the process is going to be different for different types of scenarios. Navigating in a desert scenario will be much different than navigating in a mountainous or urban setting. In a similar manner, operators should be aware of these differences as well in that training for a particular scenario may not be appropriate for other operational possibilities.

Conclusions and future research

In this study, we attempt to model the effects of elevation angle disparity, complexity, and feature type within a framework that explains the cost in efficiency of these cognitive transformations on navigational checking. The primary concern of this research was to model the effects of elevation angle disparity is terms of the sin difference of the map and FFOV angles. We also tried to establish the costs imposed by differences in levels of complexity and feature type. Although we established very clear differences in performance caused by manipulation of our variables of interest, further research is necessary. The paradigm used in this experiment was that of a same/different judgment task. As we formulate a model that incorporates the effects of various factors on the efficiency of navigational checking, we feel this paradigm is appropriate. However, "sameness" is the probable end result of most navigational checking iterations, and other paradigms may be employed and could reveal even more dramatic effects of the various manipulations. Real-time simulation using dynamic updating for visual navigation scenarios and geographic orientation decisions or possibly target acquisition and identification may yield further evidence to either support or dispute our modeled effects. Also of interest are the effects of differences in the speed of dynamic updating, (e.g., continuous at 60 Hz. or once per second). The issues surrounding map simplification also need to be investigated. How much can the number of shared features between a map and the world that it represents be reduced and still allow the pilot to know where he is? The literature reveals other variables of interest relevant to map design such as scale or zooming, color, clutter, or vibration, and more should be done with respect to applying these findings to the design of dynamic electronic, 3-D maps. Given the technological trends in aviation, the study of these factors is both timely and appropriate.

Appendix A

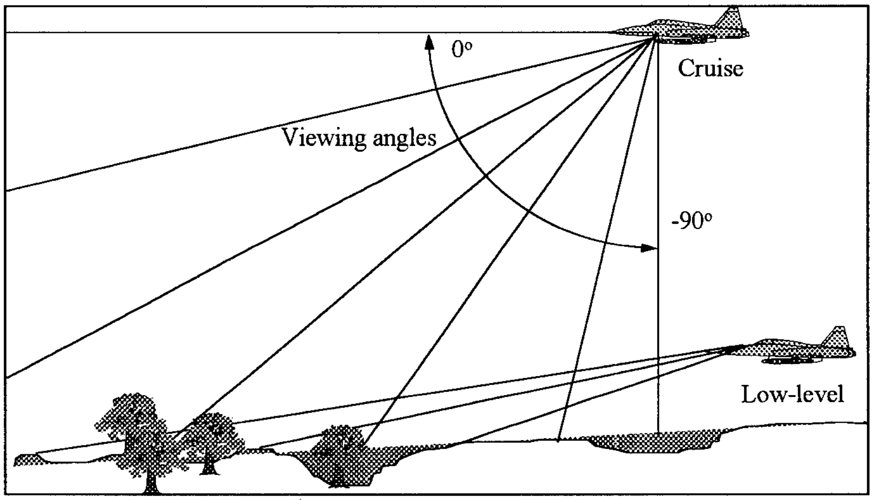
Instructions

Thank you for agreeing to participate in this experiment. It is important for the field of aviation that new designs, such as electronic maps are thoroughly tested before being implemented as part of the hardware for the general aviation cockpit, Your participation in this experiment provides us with solid empirical evidence for the possible benefits and drawbacks associated with the use of these new designs. In particular, we are interested in determining the amount of perspective or "3-D viewing" that should be incorporated in 3-D navigation maps for visual flight. This study is being conducted with grant support from the United States Navy.

In the experiment, you will see a simulated outside "world" projected on a large screen, and a simulated electronic map presented on a computer monitor. You will be shown a series of static images on both the screen and the monitor that depict what you might see if you were navigating in an aircraft.. At the start of each trial, a small "X" will direct your attention to the center of the monitor, please maintain your focus on this "X" until the images are presented. Your task will be to compare these two images and determine if they depict the same geographic location. If they are the "same" you will squeeze the trigger on the joystick. If the images depict "different" regions or scenes, then you will press the red button on the top of the joystick. You will have twenty seconds to respond to each experimental trial. After this alloted time, if you have not responded, the trial will be counted as INCORRECT and the next set of images will be presented. The object is to be as timely and accurate as possible. You will be paid an ADDITIONAL INCENTIVE if you meet a certain percentage of accuracy. After a brief practice session, the experimental trials will begin. If you have any questions, please ask them prior to the start of the experimental trials

You will notice that some of the images look as if they are projected from different angles, and in fact they are. The "world" is being presented from several different elevation angles, to simulate different altitudes that may be flown. The figure below graphically illustrates the different viewing angles that can be encountered, depending on aircraft altitude and where the

pilot is looking. You will see the “world” as if looking through a camera on the aircraft that was aligned with one of the viewing angles and pointed at that particualr spot on the ground.



Likewise, the “map” will also have a similar look as several different elevation angles will be presented as well. Additionally, the map will always be presented in a “track-up” position, meaning, there will be NO azimuth differences between the map and the world. For example, if the map is at 270°, so will be the world.

When “different” scenes are presented, differences between some of the images may at times be very subtle. Differences could be found with roads, bridges and buildings, or with rivers, mountain ranges, or plateaus. The images may look identical except for one or two changes. This would necessitate a “different” response. Due to the nature of the computer equipment and the “realism” of the task, there will be some noted differences between the two views that are not necessarily to be construed as requiring “different” responses. Although color is useful in map design, color patterns will not be uniform from the map to the world view. From your experience in flying, it is seldom that the colors of a map match those in the world view over which you are flying. Additionally, the resolution of distant objects in the world view may be such that they are very hard to identify or even see. The map does not have this limitation. Again, realism would suggest that when looking outside, distant objects are harder to see and discern than closer objects. Distant objects depicted on the map that are not in the world view are not relevant to the task at hand. Finally, because the map and the world may be presented from different elevation angles, it is important to note that some information that is not in one view, may be picked up by

the periphery of the other view with a different viewing angle. Again, this situation is not to be considered a "different" trial. Comparison of the common features in both views will be sufficient to make a judgment. If there is any confusion about these instructions, I will explain it more clearly during the practice trials.

The session will last approximately 1.5 hours with a 5 min break halfway through. You will be paid $5 per hour with a $1 BONUS for an accuracy of 90% or better.

Appendix B

Post-experiment questionnaire

At what point did the scenes depicted start looking "familiar"?

1/4 way through 1/2 way through 3/4 way through never

Did familiarity with the scenes make same/different judgments any easier?

What kinds of features were MOST helpful when making judgments? In other words, what features helped you compare the two views faster? Circle all that apply

roads/highways

rivers

hills/peaks

towers

buildings

bridges

nothing was more helpful than others

other (please indicate_______________)

Please check with me at the end of the semester if you wish to know the results of this study

AGAIN, THANKS FOR YOUR PARTICIPATION!!!!

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